A STUDY FOR THE DETERMINATION OF THE INDENT DEPTH AND CONFIGURATION FOR THE MAXIMUM RELIABILITY CONNECTIONS WHEN NICKEL PLATED COPPER WIRE IS CRIMPED INTO GOLD PLATED CONNECTOR CONTACTS

FINAL REPORT
(for period 1 July 1966 to 1 May 1967)

Contract No. NAS8-20407
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May 1967

ABSTRACT

This study for the determination of Indent Depth and Configuration for Maximum Reliability Connections of Nickel-Plated Copper Wire in Gold-Plated Connector Contacts prepared and obtained data from over 200 different contact-wire combinations. The independent variables were: contact type, contact size, wire size, indent configuration, and indentor spacing. The data were processed and analyzed.

The conclusions reached are that the double indent configuration yields significantly greater tensile strength for the NAS and MS contacts than was obtained with a single indent configuration. In addition, the extent of variability of the tensile strength is less for the double indent configuration than for the single indent configuration. The data revealed that crimp contact tensile strength equal to the strength of the wire may be obtained for an optimum double indent indentor spacing.

Based upon the derived data for the specified indentor settings, the above conclusion is indicated but is not considered valid for the Bendix Type CE crimped contacts. The data do indicate that the optimum range of indentor settings may be 2.0 to 4.0 thousandths greater for the CE-type contacts than for the NAS and MS types when a double indent configuration is utilized.

The study revealed that the sample specimens crimped with the double indent configuration yielded less increase in voltage drop as a function of the environmental stressing.

The study revealed that the voltage drop characteristics of the Bendix Type CE contacts were not significantly changed by the stress of ten days of salt fog.

The study revealed that the voltage drop characteristics of the NAS and MS type contacts were significantly degraded by the exposure to ten days of 1/2 percent salt fog at +50°C.

The reason for the very small voltage drop change for the CE-type contacts as a function of the environmental stress tests is not immediately apparent. The CE contacts were not further analyzed or investigated.

The dimensional changes in any of the contact groups were not considered as being significant.

FOREWORD

This is a documentary report on the study effort for the determination of Indent Depth and Configuration for Maximum Reliability Connections of Nickel-plated Copper Wire in Gold-plated Connector Contacts, Marshall Space Flight Center Contract No. NAS 8-20407. The technical guidelines for this study are given here.

STATEMENT OF WORK

The Contractor shall prepare and test the following crimp connections. The connections shall be made using MIL-C-27500 wire and the contact types and sizes and wire sizes listed.

Contact Type	Contact Size	Wire Size	Indentor* Spacing	Quantity Double Indent	Quantity Single Indent
NAS 1662	20	22	0.034 0.037 0.040 0.043	100	100
NAS 1662	20	20	0.037 0.040 0.043 0.046		
NAS 1662	16	20	0.037 0.040 0.043 0.046		
NAS 1662	16	16	0.043 0.046 0.050 0.054		
NAS 1663	20	22	0.034 0.037 0.040 0.043		
NAS 1663	20	20	0.037 0.040 0.043 0.046	100	100

*(Indentor spacing is the dimension "A" as specified by MS 3191).

Contact Type	Contact Size	Wire Size	Indentor* Spacing	Quantity Double Indent	Quantity Single Indent
NAS 1663	16	20	0.037 0.040 0.043 0.046	100	100
NAS 1663	16	16	0.043 0.046 0.050 0.054		
MS 3192	20	22	0.034 0.037 0.040 0.043		
MS 3192	20	20	0.037 0.040 0.043 0.046		
MS 3192	16	20	0.037 0.040 0.043 0.046		
MS 3192	16	16	0.043 0.046 0.050 0.054		
MS 3193	20	22	0.034 0.037 0.040 0.043		
MS 3193	20	20	0.037 0.040 0.043 0.046	100	100

*(Indentor spacing is the dimension "A" as specified by MS 3191).

Contact Type	Contact Size	Wire Size	Indentor* Spacing	Quantity Double Indent	Quantity Single Indent
MS 3193	16	20	0.037 0.040 0.043 0.046	100	100
MS 3193	16	16	0.043 0.046 0.050 0.054		
Bendix CE	20(pin)	22	0.034 0.037 0.040 0.043		
Bendix CE	20(pin)	20	0.037 0.040 0.043 0.046		
Bendix CE	16(pin)	20	0.037 0.040 0.043 0.046		
Bendix CE	16(pin)	16	0.043 0.046 0.050 0.054		
Bendix CE	20(socket)	22	0.034 0.037 0.040 0.043		
Bendix CE	20(socket)	20	0.037 0.040 0.043 0.046		
Bendix CE	16(socket)	16	0.043 0.046 0.050 0.054	100	100

*(Indentor spacing is the dimension "A" as specified by MS 3191).

The test specimens for each wire size, contact size and indentor spacing and configuration combination shall be divided into two groups of 50 each. Twelve samples shall be selected from each group and identified and subjected to the following tests and measurements:

1. Voltage drop test per MIL-T-22520B
2. Deformation of crimp barrel per MIL-T-22520B
3. Axial bending per MIL-T-22520B
4. Depth of indent in contact barrel. (Depth of indent corresponds to indentor spacing. It is the indentor spacing plus the spring back).

Following the above examinations, one group (including the 12 selected for measurements), shall be tensile tested per MIL-T-22520B. The other group (also including the 12 selected from this group for measurements), shall be subjected to the following environmental test per MIL-STD-202B:

1. Thermal Shock per Method 107A - Test Condition "C"
2. Temperature Cycling per Method 102A - Test Condition "D"
3. Life Test per Method 108 - Test Condition "B"
4. Vibration Test per Method 204A - Test Condition "B"

Following environmental tests, tests 1 and 4 (voltage drop and indent depth) above shall be repeated on the 12 specimens that were tested prior to the environmental tests, and last, this group shall be tensile tested per MIL-T-22520B. All test results shall be recorded and individual test specimens identified, where necessary, in order that test results may be correlated. The contractor shall compute the arithmetic mean and the standard deviation for each test for all wire-contact-crimp-indent combinations tested.

The contractor shall furnish two copies and one reproducible of all test data, computations, and other information pertinent to the performance of this test program. Documents shall be delivered in accordance with instruction from the Contracting Officer. All test specimens shall be retained by the contractor until contract is completed and then discarded.

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1. PROGRAM DELINEATION

1.1 The Study in General

Upon receipt of the contract, procurements were initiated for the required gold-plated contacts, nickel-plated wire, crimping tools, and gages. The specimen identification format was reviewed and finalized. A program was prepared to generate the required forms for the recording of the specified data utilizing electronic data processing means. Work orders were issued to prepare the required specimens. Data were taken as specified in the Statement of Work prior and after environment exposure. The derived data were processed to yield the summary information, data comparisons, and the curves presented herein.

1.2 Contacts

The required and specified contacts were procured directly from approved manufacturers currently in production. This eliminated problems, such as contamination from lubricants, which have arisen in the past when contacts from jobber stocks have been used and also the possibility of obtaining contacts to the same specification which had been fabricated by more than one company. The purchase orders issued are given in appendix A.

1.3 Wire

The responsive quotations from acceptable sources for nickel-plated and Teflon insulated copper wire, without a DO rating, indicated probable delivery of approximately 20 weeks. The Space Flight Center could supply only two of the required three wire sizes as GFM. In order not to delay the program, it was agreed to purchase the nickel-plate wires from more than one source. A total of seven sources were utilized and these are given as appendix A.

1.4 Crimping Tools

To provide uniform crimping action, with flexibility in indentor configuration and spacing, a Class II MIL-T-22520 cycle-controlled, manual feed pneumatic crimping tool was procured. This tool was assembled and mounted with associated air filter, regulator, oiler, and reservoir for use in the crimping of the specimens for this task only. Figure 1 is a photograph os this installation. The purchased tool and associated accessories are listed in appendix A.

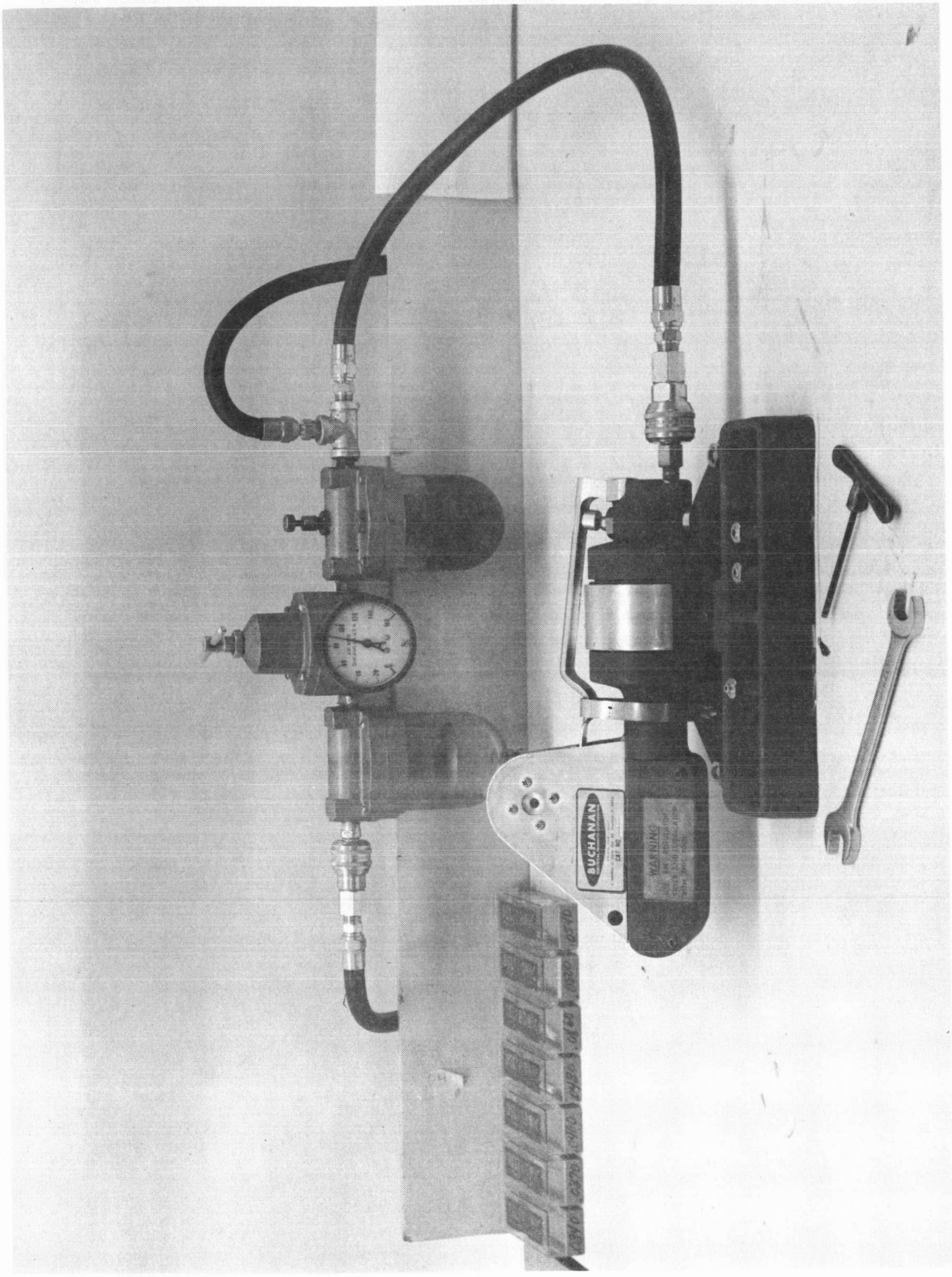

Figure 1. A Cycle-Control, Manual Feed Pneumatic Crimping Tool Installation

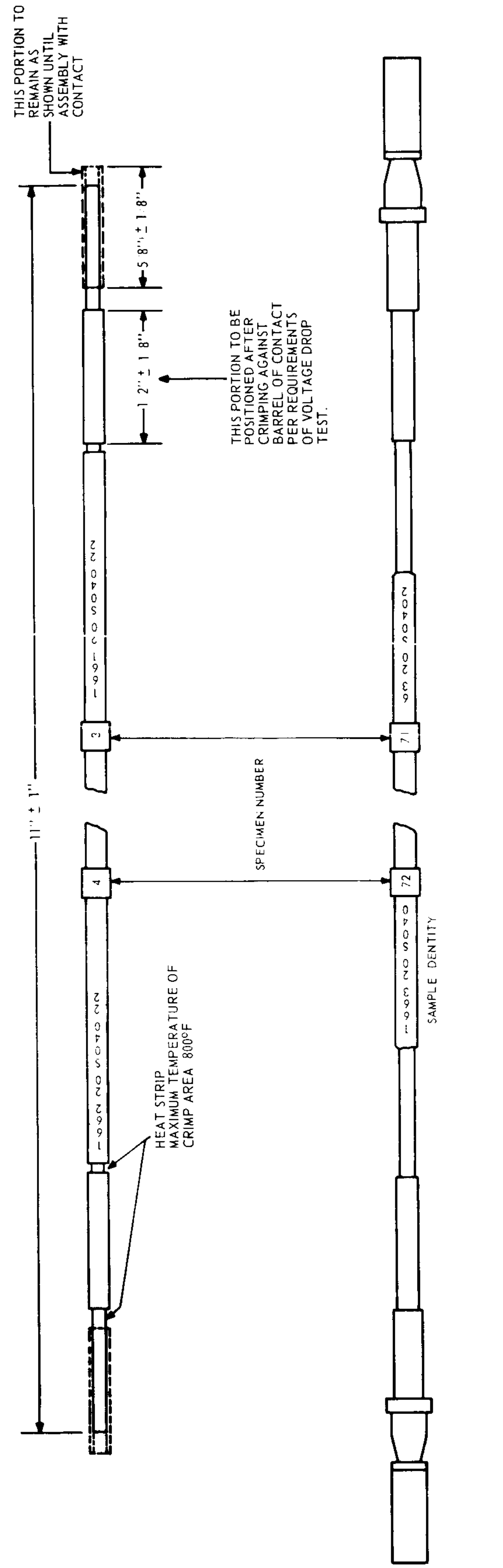

Figure 2. Wire Strip for Indent Study Typical

1.5 Gages

Seven wire gages corresponding to the specified indentor spacings were procured and assigned to the crimping tool. An inspector's dial indicating gage was procured and adapted by the tool and gage department for depth measurements. A precision jeweler's chuck and optical comparator were available for the determination of axial bending and deformation. A test jig was fabricated to aid in the measurement of voltage drop. Calibrated current sources and millivolt meter were available from the Metrology Laboratory.

1.6 Sample Preparation

The individual lots of sample specimens were prepared from 60-foot lengths of the specified wire stamped with the lot identity nomenclature. After heat stamping, the wire was sintered to permanently affix the stamping to the Teflon insulation. The wire was cut into lengths between 11 and 12 inches. The insulation was heat "ringed" on each end by semiautomatic heat strippers in accordance with the sketch in figure 2. The bundles of 60 wires were then ready to be crimped.

The crimping tool with either the single or the double indentor cam assembly was set to the desired indentor spacing, and the 100 or more specimens were prepared. Prior to crimping, heat shrinkable number bands were attached to each end of the sample wires. It was also a practice not to remove the heat stripped insulation until just prior to crimping to guarantee a minimum of disturbance of the lay of the wire stranding.

1.7 Sample Identification

To identify each of the groups of sample specimens, a nomenclature format was prepared. The format was fully descriptive of the parameters specified for that group of the crimped specimens. The format is given in table 1 following.

TABLE 1

NOMENCLATURE FORMAT FOR GROUPS OF SAMPLE SPECIMENS

	Contact Type	Contact Size	Indent	Indentor Spacing	Wire Size
Abrev.	C T	C S	I	I S	W S
IBM Col.	1 2 3 4	6 7	9	10 11 12	14 15
	1 6 6 2	2 0	S	0 3 4	2 2
	1 6 6 3	1 6	D	0 3 7	2 0
	3 1 9 2			0 4 0	1 6
	3 1 9 3			0 4 3	
	C E P I			0 4 6	
	C E S O			0 5 0	
				0 5 4	
				0 3 2	
				0 5 9	

To facilitate subsequent sorting in data processing, each of the lots was assigned a three-digit number to be located in columns 77-78-79 of the data card. These numbers are identified in appendix B. Specimen sample numbers in each lot were assigned from 1 through a maximum of 120 as required (data card columns 17, 18, 19).

1.8 Data Breakdown and Format

To separate the data, it was necessary to idenify the different blocks within each group. The following alphabetical notation was assigned and entered in Column 46:

A - Tensile strength only from 38 specimens.
B - Indent depth, voltage drop, deformation, axial bending, and tensile strength from 12 specimens.
E - Tensile strength only from 38 specimens environmentally stressed.
S - Indent depth, voltage drop, deformation and axial bending prior to environmental exposure.
Indent depth and voltage drop after environmental exposure.
Ten-day salt fog exposure followed by voltage drop and tensile strength.

Z - A tensile strength only for indentor spacings outside the specified range

All data was recorded either directly on data cards or in the data logs. The information in the data logs was transferred to cards.

The format prescribed for the data cards is given in figure 3.

Identification of the data specified for the columns of the card is given here.

Columns 1 through 19	-	are utilized to identify each sample specimen, paragraph 1.7.
Columns 21 through 32	-	measured indent depth (1/10 mil.)
Columns 34, 35, 36	-	voltage drop (1/10 MV)
Columns 38, 39, 40	-	deformation diameter (mil)
Columns 42, 43, 44	-	axial bending (1/10 mil)
Column 46	-	data group
Columns 48 through 59	-	measured indent depth after environmental expsure (1/10 mil)
Columns 61, 62, 63	-	voltage drop after environmental exposure (1/10 MV)
Columns 65, 66, 67, 68	-	tensile strength (1/10 pound)
Columns 71, 72, 73	-	voltage drop after salt fog exposure (1/10 MV)
Columns 77, 78, 79	-	numeric group identity and sorting number

1.9 Tensile Data, "A" Only

Upon the completion of each of the 100 or more crimp connections of one of the specified lots, a minimum of 30 were removed for immediate tensile testing. These data were transferred to cards. A modified computer program was prepared and the tensile data processed. The results were supplied as an Interim Report. The Statistical Analysis, presented in section 2 and appendix E, is based upon this data.

This procedure gave an early indication of the crimping procedure. The results were evaluated and compared for uniformity.

1.10 Crimp Data, "B"

The data specified for two samples of 12 specimens from each of the lots were taken and recorded.

E7502

CT	CS	I	IS	WS	SN	I	DEPTH MILS
1662	20	S	034	22	001		
1663	20	D	037	20	007		414412422420
3192	16	S	043	16	005		
3193	16	D	037	20	017		442441440438
CEP1	20	S	034	22	009		
CESO	20	S	037	20	011		437441
CESO	16	D	050	20	013		
CESO	16	D	046	20	015		525520525520

VDM (34–36)	DDM (37–40)	ABM (41–44)	E (45–46)	I DEPTH MILS (48–59)	VDM (60–63)	TS# (64–68)	VDMS (70–73)	LOT (77–79)
			A			0205		001
054	077	050	B			0346		045
			E			0566		089
043	107	075	S	437432442436	057	0229	057	117
			A			0237		129
056	075	075	B			0248		169
			Z			0304		213
055	109	062	B			0330		308

Figure 3. Data Format

1.10.1 Indent Depth

The depth of indent of a crimped contact is defined as the indentor spacing plus the spring back of the wire and contact barrel. It is always greater than the indentor spacing. The accepted method of measurement is by the use of pointed micrometers. Since this procedure is rather slow and tedious, an inspector's bench gage with dial indicator with point contacts was assembled and calibrated. The dial indicator was capable of reading 0.0001 inch, but due to other variables the accuracy of measurement after calibration was considered ±0.0005 inch, nominal. The variables are those primarily associated with measurements between points and the skill of the operator. The measurements were checked on a sample basis for all groups by the micrometer technique by a mechanical inspector.

1.10.2 Axial Bending

The measurement of axial bending per MIL-T-22520B was accomplished by mounting the contact in a precision jewelers chuck, rotating in a vee block, and measuring the runout on an optical comparator.

1.10.3 Deformation

The measurement of deformation or maximum diameter per MIL-T-22520B was accomplished with the same instruments used for axial bending. The clamped crimp contact was rotated and the maximum diameter of the crimp area was measured.

1.10.4 Voltage Drop

The measurement of voltage drop was accomplished with a test jig which held the 12" specimens in spring clips making electrical and mechanical contact at each terminal and at the bared area 1/2 inch from the crimp line. A calibrated power supply provided the specified current and a vacuum tube voltmeter measured the voltage drop from the crimp barrel rim and the stripped area on the wire.

1.11 Environmental Stress

Twelve crimp data specimens and 38 unmeasured specimens from each group were combined to form the 50 specimens required for environmental stress exposure. The 9,200 connections were exposed together at the same time. The exposure report is given in appendix C.

1.12 Tensile Data "A" and "B"

The other 12 crimp data specimens and the remaining unmeasured specimens for each group were tensile tested. The data from this tensile test were combined with the 30 percent tensile test data to give the tensile strength data for the specimens not exposed to the environmental stress.

1.13 Tensile Data "E"

At the completion of the environmental stress exposure, the 38 unmeasured specimens from each group were tensile tested. This provided the values of tensile strength of the crimped connection after exposure to the environmental stress.

1.14 Crimp Data "E"

The 12 previously measured and environmentally stressed specimens were remeasured for indent depth and voltage drop. This provided information on possible degradation of the crimped connections.

1.15 Salt Fog Exposure

In accordance with a contract amendment, the 12 measured specimens from the environment test were exposed to 10 days of salt fog. The temperature was +50°C and the salt concentration was 0.5 percent. Appendix C includes the salt fog test report of the Environmental Test Laboratory.

1.16 Salt Fog Tensile and Voltage Drop Data, "S"

At the conclusion of the salt fog exposure, the 12 measured specimens were subjected to a third voltage drop measurement followed by final tensile data. These gave information on the extent of degradation of the crimped contacts mechanical and electrical properties as a function of the salt fog stress.

1.17 Supplementary Groups

Variations in the uniformity of the mean tensile strength prompted the fabrication of supplementary groups for analysis. The first lot was prepared to answer questions concerning apparent non-uniformity of tensile strength as a function of indentor spacing within the specified indent range for a particular contact and wire combination. The only uncontrolled variable was the wire. To confirm this supplementary groups were prepared from stamped, cut, and stripped overrun wires with the contacts crimped to an indentor spacing different from that specified on the wire stamping. The second lot of supplementary groups was made up of sample specimens crimped to a fifth indentor spacing beyond the specified range. These are identified by 200 series number in Columns 77, 78, and 79. A third lot of supplementary groups was prepared to provide continuity in the statistical analysis. These are identified with a series 300 number in Columns 77, 78, and 79.

1.18 Data Processing

1.18.1 General

Due to the large volume of data generated by the multi-parameter measurements of the specified crimped contact assemblies, electronic data processing assistance was an integral part of the program effort. Although it is possible to go directly from analogue outputs via A to D converters or digitizers to cards, punched tape or magnetic tape, this was not resorted to because of time and the desire to have an original data record. Such a direct process would be very helpful if, for example, the daily data could be processed overnight and be available as "rushes" the next morning for review. Errors and trends could be identified and appropriate action taken.

1.18.2 Original Data

The data as observed or measured were recorded or retained in its original form or format. The tensile data as recorded by a pen recorder on charts were retained with the pulled specimens segregated in groups corresponding to the nomenclature given in appendix B. The tensile statistics were either transferred directly to cards, as in the case of the 30 percent tensile only specimens, or transferred to the data log books. The other measurements of indent depth, voltage drop, axial bending, and deformation were recorded in the data log books and then transferred manually to cards.

1.18.3 Data Correction

The processes of entering data in the data logs, the punching of the data cards, the verification of the data cards, and the scanning of a printout listing of the cards provide opportunities to locate and correct or adjust gross errors and omissions in the gathered data.

The processed data, with their listing of minimum, maximum, mean, and standard deviation values for each group, provide the second opportunity to review for data variations and errors. This is the most logical point to observe and determine bias due to measurement errors either instrument or operator. Adjustments can be made and the process repeated until the error is considered to be within acceptable limits.

2. STATISTICAL SIGNIFICANCE, SINGLE VS. DOUBLE INDENT

The test data provided, for each connector type, number paired sets of average tensile test values and their standard deviations. Each of the sets of 32 tensile tests was obtained from a different combination of contact size, wire size, and indentor spacing. The significance of the differences between pairs was evaluated for each connector type by use of the Wilcoxon Signed-Ranks Test.*

2.1 Tensile Strength Value

2.1.1 Test Hypothesis

The test was first used to determine whether, other conditions being comparable, the double indent gave greater tensile strength than the single indent to such an extent that the difference could not be ascribed to chance.

2.1.2 Significance of Strength Difference

The data for the test of significance are given in table 2. The table gives also the test statistic T, the number of pairs of values, and the value of α , the level of significance or probability that the results would be obtained by chance alone.

A value of 0.025 for the level of significance was accepted as evidence against the chance hypothesis and for the test hypothesis. Thus the results may be taken to show that the double indent gives significantly higher tensile strength in general than the single indent, at least for all connector types except the Bendix CESO.

The original set of samples made with the Bendix CESO connector did not include the combination of a size-16 contact and a size-20 wire. This reduced the number of paired observations of tensile strength from 16 to 12. When this gap in the table was discovered to be merely a typographical error in preparation of the contract, the "missing" samples were prepared and measured. Inclusion of these samples did not alter the findings with respect to the Bendix CESO connector. With the added data, the mean values of tensile strength for single and double indent were 32.8 and 33.2 pounds respectively.

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*M. G. Natrella, "Experimental Statistics" National Bureau of Standards Handbook 91, pp. 16-5, 16-9, T-79 Washington, D.C., U.S. Government Printing Office, 1963 Reprinted from Army Materiel Command Engineering Design Handbook, Ordnance Pamphlet 20-113 and 20-114.

TABLE 2
COMPARISON OF AVERAGE TENSILE STRENGTHS

CONNECTOR	INDENT			WILCOXON TEST		
	SINGLE	DOUBLE	% CHANGE	T	N	α
NAS 1662	32.4 lb	38.6 lb	19.1	5	16	0.005*
NAS 1663	29.8	38.2	28.2	0	16	0.005*
MS 3192	33.7	40.0	18.7	0	16	0.005*
MS 3193	32.3	38.0	17.6	8	16	0.005*
BENDIX CEPI	33.3	35.5	6.6	30	16	0.025*
BENDIX CESO	34.9	34.8	-0.3	41	12	0.025

*AN ASTERISK INDICATES THAT THE RESEARCH HYPOTHESIS WAS ACCEPTED.

2.2 Tensile Strength Uniformity

The Wilcoxon test was also applied to the sets of paired values of the coefficient of variability (i.e., the standard deviation divided by the mean value).

2.2.1 Test Hypothesis

The comparison was made to test the hypothesis that otherwise equivalent crimped connections have a lower variability in tensile strength with double indent than with single indent.

2.2.2 Significance of Differences

The data for this comparison are given in table 3. As with the preceding test for strength values, the test hypothesis was accepted at a level of significance of 0.025 or less for all connector types except the Bendix CESO.

Note: A full delineation of the Statistical Analysis performed is given in appendix E.

TABLE 3
COMPARISON OF RELATIVE VARIABILITY IN TENSILE STRENGTHS

CONNECTOR	INDENT			WILCOXON TEST		
	SINGLE	DOUBLE	% CHANGE	T	N	α
NAS 1662	6.14%	2.13%	-65.3	0	16	0.005*
NAS 1663	6.51	2.35	-63.9	0	16	0.005*
MS 3192	4.07	2.95	-27.5	26.5	16	0.025*
MS 3193	5.72	3.11	-45.6	9	16	0.005*
BENDIX CEPI	4.44	3.52	-20.7	29	16	0.025*
BENDIX CESO	5.62	5.40	-3.91	33	12	0.025

*AN ASTERISK INDICATES THAT THE RESEARCH HYPOTHESIS WAS ACCEPTED.

3. INVESTIGATION OF VARIABILITIES OF TENSILE STRENGTH

3.1 General

The data from the initial 30 percent tensile only groups were processed and are summarized in table 4. Included in this presentation is summary information from supplementary groups from which data were obtained during the course of this investigation.

Two points are recorded for each group: (1) the mean tensile strength and (2) standard deviation. The data indicate generally greater and more uniform tensile strength for the double indent configuration. This conclusion is based upon the comparison of paired groups with the same indentor spacing, e.g., 1662-20-S034-22 vs. 1662-20-D034-22. The double indent configuration group has a lower standard deviation in 74 out of 96 comparisons and higher tensile strength in 80 out of 96 comparisons.

The maximum mean value of tensile strength for any of the specified wire and contact combinations was obtained with the double indent configuration. The single indent configuration exhibited less spread in tensile strength as a function of indentor spacing than did the double indent configuration.

The data also indicated anomalies or variations which did not appear to be functions of indentor spacing. This is considered as only an indication due to the limited sample population of only four different indentor spacings. This was further investigated by the fabrication and tensile testing of several hybrid groups. The results of this investigation did give some credibility to the suggestion that tensile strength varies significantly as a function of wire source.

The range of tensile strength mean values for the double indent configurations are greater than the corresponding single indent groups. This was so pronounced in the CE-16 groups that an investigation was made into the possibility of fractured wires. This was not confirmed. A review of the specifications for the NAS, MS, and CE contacts indicates a single dimensional difference for the crimp barrel of 0.003 inch less inside diameter for the CE contacts. This difference results in a greater reduction of wire cross section at the lower double indent spacings. This reduces the tensile strength of the wire due to necking and possible work hardening.

TABLE 4

MEAN TENSILE STRENGTH AND STANDARD DEVIATION,
FOR TYPE NAS 1662 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	15 DIMT > SIMT 1 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	16 DISD < SISD 0 DISD > SISD
1662-20( )032-22		23.50*				0.83	
( )034	21.97	24.60	+	2.63	0.98	0.33	+
( )037	19.35	23.68	+	4.33	0.59	0.38	+
( )040	19.18	19.27	+	0.09	0.94	0.61	+
( )043	18.37	16.56	-	1.81	0.89	0.61	+
Spread	3.60	8.04					
1662-20( )034-20		32.69*				1.27	
( )037	28.97	36.12	+	7.15	2.10	0.40	+
( )040	29.02	35.73	+	6.71	1.81	0.78	+
( )043	28.53	30.97	+	2.44	1.79	0.76	+
( )046	26.62	30.08	+	3.46	2.20	0.68	+
Spread	2.40	6.04					
1662-16( )037-20	31.10	35.69	+	4.59	3.33	0.65	+
( )040	34.89	36.24	+	1.35	1.49	0.49	+
( )043	36.18	36.78	+	0.60	2.15	0.72	+
( )046	34.44	34.64	+	0.20	1.96	0.75	+
Spread	5.08	2.14					
1662-16( )040-16		58.57*				2.24	
( )043	46.72	65.21	+	18.49	3.42	1.75	+
( )046	46.31	65.67	+	19.36	3.43	1.62	+
( )050	49.87	65.28	+	15.41	2.85	1.24	+
( )054	47.00	60.96	+	13.96	2.78	1.21	+
Spread	3.56	4.71					

* Not included in computation of spread.

TABLE 4 (Continued)

MEAN TENSILE STRENGTH AND STANDARD DEVIATION,
FOR TYPE NAS 1663 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size	Indentor Spacing / Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	16 DIMT > SIMT / 0 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	16 DISD < SISD / 0 DISD > SISD
1663-20(	)032-22		22.66*				0.22	+
(	)034	19.84	23.13	+	3.29	0.64	0.46	+
(	)037	19.45	21.99	+	2.54	0.96	0.54	+
(	)040	19.41	21.25	+	1.84	0.79	0.59	+
(	)043	16.73	18.48	+	1.75	0.90	0.42	+
Spread		3.11	4.65					
1663-20(	)034-20		30.98*				1.51	
(	)037	29.10	34.43	+	5.33	2.27	0.49	+
(	)040	27.77	32.65	+	4.88	3.14	0.55	+
(	)043	23.33	30.59	+	7.26	1.30	0.74	+
(	)046	21.07	29.14	+	8.07	1.54	0.64	+
Spread		8.03	5.29					
1663-16(	)037-20	31.26	34.99	+	3.73	1.74	0.67	+
(	)040	31.74	36.32	+	4.58	1.34	0.89	+
(	)043	31.01	36.59	+	5.58	3.05	0.88	+
(	)046	29.96	34.78	+	4.82	1.58	0.85	+
Spread		1.78	1.81					
1663-16(	)043-16	46.13	63.09	+	16.96	3.27	1.41	+
(	)046	45.79	66.81	+	21.02	3.23	1.43	+
(	)050	41.80	66.08	+	24.28	2.58	2.13	+
(	)054	43.28	60.98	+	17.70	4.06	2.14	+
Spread		4.33	5.83					

* Not included in computation of spread.

TABLE 4 (Continued)

MEAN TENSILE STRENGTH AND STANDARD DEVIATION, FOR TYPE MS 3192 CRIMPED CONTACTS AS A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	15 DIMT > SIMT 0 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	10 DISD < SISD 6 DISD > SISD
3192-20( )034-22	20.74	23.82	+	3.08	0.98	0.29	+
( )037	20.27	24.67	+	4.40	1.15	1.18	-
( )040	19.71	25.16	+	5.45	0.99	0.47	+
( )043	17.92	21.32	+	3.40	0.60	1.65	-
Spread	2.82	3.84					
3192-20( )037-20	31.22	35.66	+	4.44	1.60	0.87	+
( )040	30.31	36.09	+	5.78	1.45	1.71	-
( )043	30.98	33.45	+	2.47	1.09	1.45	-
( )046	29.84	33.94	+	4.10	1.65	0.89	+
Spread	1.38	2.64					
3192-16( )037-20	29.09	32.41	+	3.32	0.77	0.46	+
( )040	32.27	33.80	+	1.53	0.79	0.55	+
( )043	31.13	36.87	+	5.74	0.73	1.13	-
( )046	31.20	36.80	+	5.60	0.75	0.59	+
( )050		34.20*				1.80	
Spread	3.18	4.46					
3192-16( )043-16	56.44	66.30	+	9.86	1.96	2.60	-
( )046	56.94	67.00	+	10.06	2.84	1.76	+
( )050	55.02	66.70	+	11.68	2.57	1.41	+
( )054	46.69	65.70	+	19.01	2.11	0.68	+
Spread	10.25	1.30					

* Not included in computation of spread.

TABLE 4 (Continued)

MEAN TENSILE STRENGTH AND STANDARD DEVIATION, FOR TYPE MS 3193 CRIMPED CONTACTS AS A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	14 DIMT > SIMT / 2 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	12 DISD < SISD / 4 DISD > SISD
3193-20( )032-22		21.10*				0.56	
( )034	23.63	26.62	+	2.99	1.20	0.45	+
( )037	23.41	25.56	+	2.15	2.23	0.62	+
( )040	24.49	25.31	+	0.82	1.35	0.64	+
( )043	23.12	21.74	-	1.38	2.58	1.56	+
Spread	1.37	4.88					
3193-20( )037-20	29.12	33.00	+	3.88	2.20	1.00	+
( )040	25.96	34.29	+	8.33	2.32	1.02	+
( )043	25.21	32.40	+	7.19	1.68	0.92	+
( )046	24.00	30.41	+	6.41	1.69	1.70	-
Spread	5.12	3.88					
3193-16( )037-20	29.66	27.34	-	2.32	0.52	1.30	-
( )040	29.05	29.56	+	0.51	1.02	0.53	+
( )043	28.25	32.01	+	3.76	0.46	0.42	+
( )046	26.65	32.38	+	5.73	0.68	0.70	-
( )050		32.84*				2.39	
Spread	3.01	5.04					
3193-16( )043-16	50.48	60.33	+	9.85	1.82	2.09	-
( )046	51.33	64.58	+	13.25	2.95	1.98	+
( )050	52.13	69.27	+	17.14	2.54	1.87	+
( )054	49.99	63.96	+	13.97	3.20	1.47	+
Spread	2.14	8.94					

* Not included in computation of spread.

TABLE 4 (Continued)

MEAN TENSILE STRENGTH AND STANDARD DEVIATION, FOR BENDIX TYPE CE (PIN) CRIMPED CONTACTS AS A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	11 DIMT > SIMT 5 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	11 DISD < SISD 5 DISD > SISD
CEPI-20( )034-22	23.20	23.06	-	0.14	0.85	0.49	+
( )037	23.84	24.89	+	1.05	0.84	0.49	+
( )040	23.82	25.97	+	2.15	0.68	0.58	+
( )043	23.32	25.57	+	2.25	1.21	0.78	+
( )046		19.09*				0.57	
Spread	0.64	2.91					
CEPI-20( )037-20	23.29	25.06	+	1.77	1.99	0.94	+
( )040	26.28	26.48	+	0.20	1.64	0.85	+
( )043	27.30	31.19	+	3.89	1.07	0.83	+
( )046	26.39	32.46	+	6.07	0.67	0.97	-
( )050		32.67*				1.68	
Spread	4.01	7.40					
CEPI-16( )037-20	24.62	21.10	-	3.52	1.92	1.06	+
( )040	27.65	26.01	-	1.64	0.69	2.10	-
( )043	27.48	33.07	+	5.59	0.75	0.79	-
( )046	27.11	34.72	+	7.61	0.49	0.99	-
( )050		31.67*				1.33	
Spread	3.03	13.62					
CEPI-16( )043-16	56.32	51.76	-	4.56	4.35	2.71	+
( )046	58.70	57.51	-	1.19	2.44	3.11	-
( )050	58.06	63.58	+	5.52	3.01	2.07	+
( )054	55.28	66.29	+	11.01	1.48	1.38	+
( )059		64.66*				1.17	
Spread	3.42	14.53					

*Not included in computation of spread.

TABLE 4 (Continued)

MEAN TENSILE STRENGTH AND STANDARD DEVIATION, FOR BENDIX TYPE CE (SOCKET) CRIMPED CONTACTS AS A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Double Indent Mean Tensile	9 DIMT > SIMT 7 DIMT < SIMT	Δ T.S.	Single Indent Std. Deviation	Double Indent Std. Deviation	7 DISD < SISD 9 DISD > SISD
CESO-20( )034-22	23.63	21.78	-	1.85	1.17	1.55	-
( )037	21.03	23.53	+	2.50	2.19	0.93	+
( )040	21.05	23.89	+	2.84	1.13	0.54	+
( )043	19.65	22.10	+	2.45	1.61	0.77	+
Spread	3.98	2.11					
CESO-20( )037-20	27.80	26.85	-	0.95	2.67	2.98	-
( )040	30.31	26.79	-	3.52	1.63	1.79	-
( )043	29.50	31.33	+	1.83	0.87	1.58	-
( )046	28.05	31.79	+	3.74	1.17	0.57	+
Spread	2.51	5.00					
CESO-16( )037-20	25.61	22.42	-	3.19	1.03	2.71	-
( )040	26.03	27.46	+	1.43	0.99	2.39	-
( )043	27.15	29.03	+	1.88	0.91	1.71	-
( )046	26.65	33.74	+	7.09	1.26	0.47	+
( )050		30.57*				0.89	
Spread	1.54	11.32					
CESO-16( )043-16	55.64	41.85	-	13.79	2.39	2.56	-
( )046	53.36	48.63	-	4.73	3.47	3.28	+
( )050	54.77	53.88	-	0.89	1.82	4.99	-
( )054	54.53	65.68	+	11.15	1.26	0.88	+
( )059		62.99*				1.79	
Spread	2.28	23.83					

*Not included in computation of spread.

3.2 Wire

The nickel-plated Teflon insulated wire used to prepare the specified sample specimens was obtained from several sources. No attempt was made to denote which source was used to fabricate any of the specimens. In addition, the supplied reels were not continuous lengths of wire.

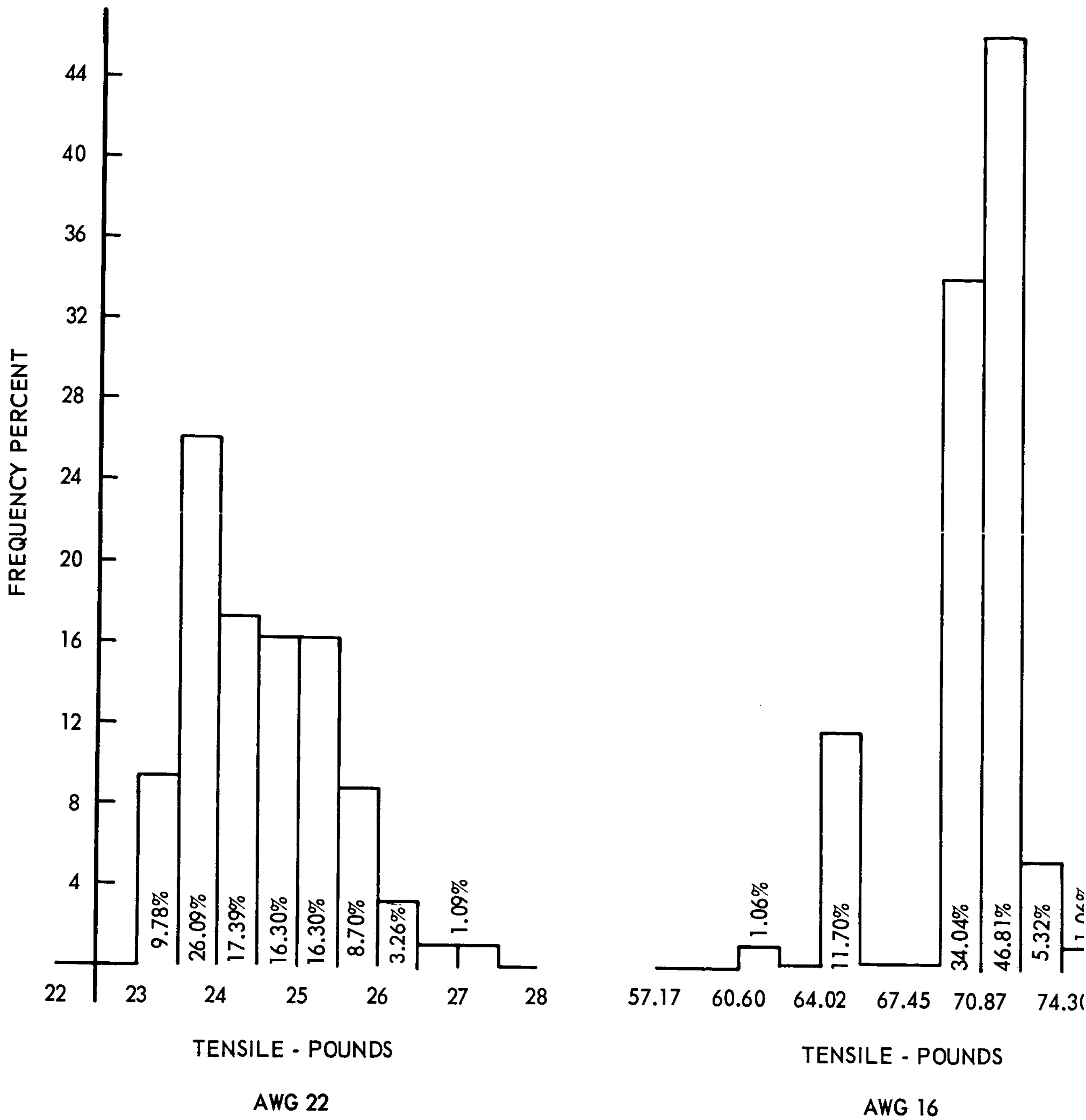
The fabrication process called for the stamping of 60-foot lengths of wire. This short length does give credit to the hypothesis that each specimen in a specified group was fabricated from identical wire. The probability of identical wire being used, group to group, cannot be easily estimated due to random lengths of supplied wire and the knowledge that greater than 60 feet of wire was stamped for several groups. Also, the operators were allowed to exercise independent judgement in the selection of numbers to stamp from the prepared list.

The tensile strength of the stranded wire is the ultimate tensile strength that can be expected for the crimped contact wire combination. Considerations which determine the tensile strength of the crimped contact and wire combination at less than ultimate tensile strength are 1) the adhesion of the plating to the copper 2) the friction present between the crimped contact barrel and the wire and 3) the amount of effective wire diameter reduction. In the case of silver-plated wire and gold-plated contacts, the crimping actions generates a metallic compression bonding of the noble metals. This tends to eliminate surface slippage. In the case of nickel and gold, metallic bonding does not take place and friction becomes an important consideration. Since nickel plating can be accomplished by more than one process (sulphamate, perborate, etc.) and the characteristics of the plating can vary as a function of the current density and the plating bath's condition (depletion, temperature, and pH), another variable is introduced.

No experimental determinations were made of possible variations in the frictional characteristics of the different nickel-plated wires and gold-plated contacts used in this study.

With labeled and cut wire lengths remaining after the fabrication of the specified specimen groups, it was possible to experimentally determine the tensile characteristics of the wire used in this study. The samples were selected so as to represent as many of the 184 stamped groups as possible. The results of this investigation are tabulated here:

E7543



FREQUENCY PERCENT
44
40
36
32
28
24
20
16
12
8
4
9.78%
26.09%
17.39%
16.30%
16.30%
8.70%
3.26%
1.09%
22
23
24
25
26
27
28
TENSILE - POUNDS
AWG 22
1.06%
11.70%
34.04%
46.81%
5.32%
57.17
60.60
64.02
67.45
70.87
TENSILE - POUNDS
AWG 16

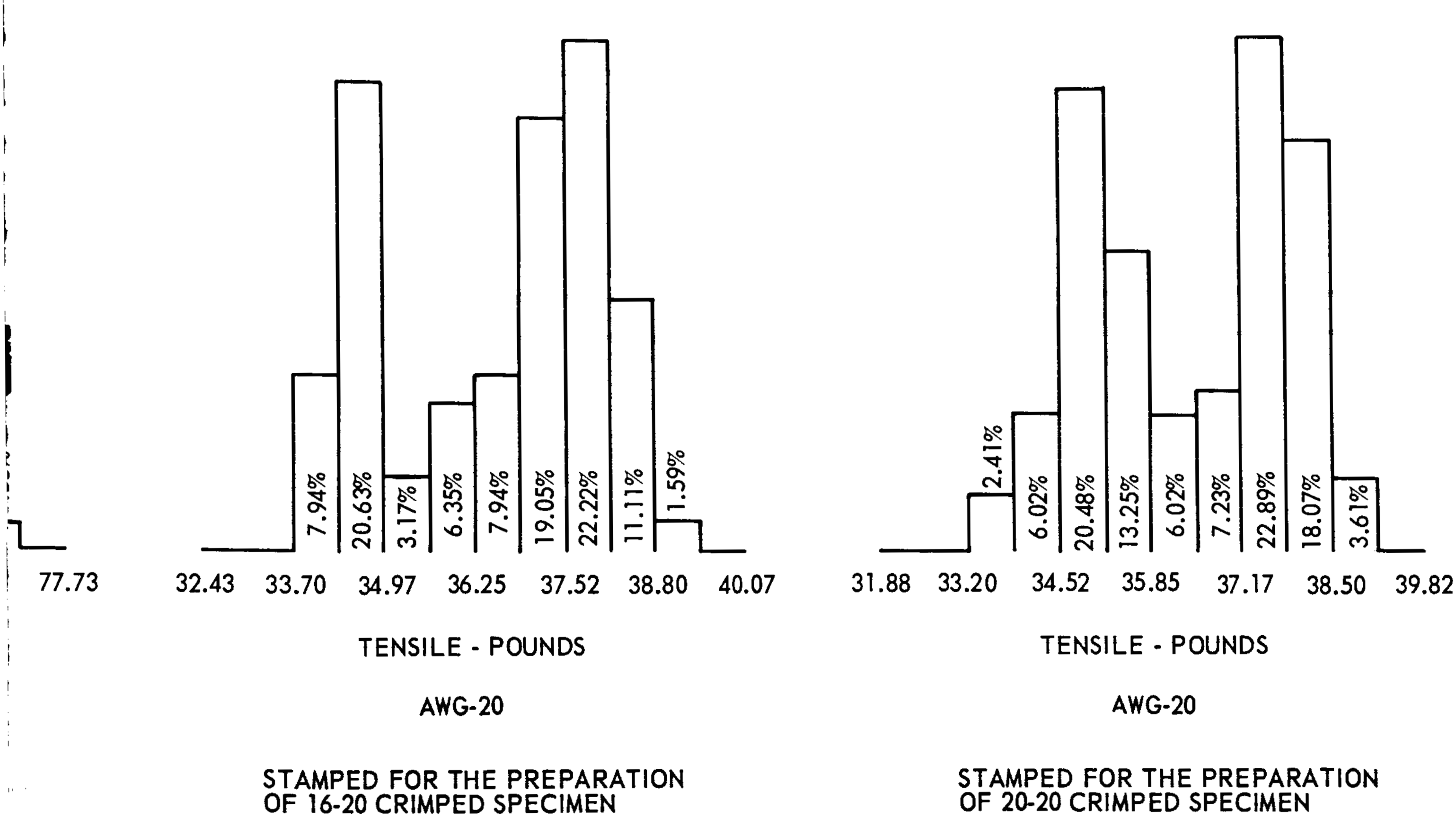


Figure 4. Frequency Distribution of Tensile Strength of Nickel Plated Copper Wire

Wire Size Contact Size	AWG-22 20	AWG-20 20	AWG-20 16	AWG-16 16
MIN	23.00	33.20	33.70	60.60 pounds
MAX	27.00	38.50	38.80	74.30 pounds
MEAN	24.47	36.39	36.53	70.23 pounds
STD. DEV.	0.86	1.48	1.53	2.45 pounds
VARIANCE	0.75	2.20	2.35	6.00 $(\text{pounds})^2$
MEDIAN	24.30	36.70	37.10	70.00 pounds
PERCENT VAR.	3.51	4.07	4.18	3.49%

The data from the four groups of sample specimens were subjected to a check for homogeneity of variance, Bartlett's test, and the results were that they were not homogeneous.

The modal characteristics can be observed in the percent frequency plots of figure 4. The size-22 wire-single mode, 20 wire-bimodal, and the size-16 wire-slightly bimodal.

3.3 Contacts

The 12 different contact types called out in the statement of work were procured from three approved manufacturers corresponding to each specification grouping, i.e., NAS, MS, and Ce. This procedure eliminated variabilities which have been reported in the industry when jobber stocks are used and when more than one source is used. The only variability could be those possible within the process and quality controls of the selected supplier.

3.4 Measurement

The ultimate tensile strength for the crimped contact specimens and wire was taken on an Instron tensile tester. Pneumatic grips were utilized. The Teflon insulation acted as a buffer material between the flat faced grips and the stranded wire. The technique was considered acceptable because the evidence of wire breakage at the grips was not excessive and did not appear to drastically modify the spread of values.

TABLE 5

MECHANISM OF TENSILE FAILURE
FOR NAS TYPE 1662 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
1662-20( )032-22				23.50	0.83	F	
( )034	21.97	0.98	S	24.60	0.33	F	20% Broke at Grip
( )037	19.35	0.59	S	23.68	0.38	F	15% Broke at Grip
( )040	19.18	0.94	S	19.27	0.61	S	
( )043	18.37	0.89	S	16.56	0.61	S	
1662-20( )034-20				32.69	1.27	F	
( )037	28.97	2.10	S	36.12	0.40	F	10% Broke at Grip
( )040	29.02	1.81	S	35.73	0.78	F 70% S 30%	
( )043	28.53	1.79	S	30.97	0.76	S	
( )046	26.62	2.20	S	30.08	0.68	S	
1662-16( )037-20	31.10	3.33	F 5% S 95%	35.69	0.65	F	10% Broke at Grip
( )040	34.89	1.49	S	36.24	0.49	F	35% Broke at Grip
( )043	36.18	2.15	S 90% F 10% Broke at Grip	36.78	0.72	F 65% S 35%	40% Broke at Grip
( )046	34.44	1.96	S	34.64	0.75	S	
1662-16( )040-16				58.57	2.24	F	
( )043	46.72	3.42	S	65.21	1.75	F	
( )046	46.31	3.43	S	65.67	1.62	F 50% S 50%	
( )050	49.87	2.85	S	65.28	1.24	S	
( )054	47.00	2.78	S	60.96	1.21	S	
Score, Contact Type and Configuration			S 15.95 F 0.05			S 8.15 F 10.85	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR NAS TYPE 1663 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
1663-20( )032-22				22.66	0.22	F	
( )034	19.84	0.64	S	23.13	0.46	F	
( )037	19.45	0.96	S	21.99	0.54	S	
( )040	19.41	0.79	S	21.25	0.59	S	
( )043	16.73	0.90	S	18.48	0.42	S	
1663-20( )034-20				30.98	1.51	F	
( )037	29.10	2.27	S	34.43	0.49	F 35% S 65%	
( )040	27.77	3.14	S	32.65	0.55	S	
( )043	23.33	1.30	S	30.59	0.74	S	
( )046	21.07	1.54	S	29.14	0.64	S	
1663-16( )037-20	31.26	1.74	S	34.99	0.67	F	
( )040	31.74	1.34	S	36.32	0.89	F	(30% Failure at Heat Strip Line)
( )043	31.01	3.05	S	36.59	0.88	F 70% S 30%	20% Failed at Heat Strip Line
( )046	29.96	1.58	S	34.78	0.85	F 20% S 80%	
1663-16( )043-16	46.13	3.27	S	63.09	1.41	F	
( )046	45.79	3.23	S	66.81	1.43	F	
( )050	41.80	2.58	S	66.08	2.13	F 20% S 80%	
( )054	43.28	4.06	S	60.98	2.14	S	
Score, Contact Type and Configuration			S 16 F 0			S 9.55 F 8.45	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR MS TYPE 3192 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
3192-20( )034-22	20.74	0.98	F 10% S 90%	23.82	0.29	F	
( )037	20.27	1.15	S	24.67	1.18	F	20% Broke at Grip
( )040	19.71	0.99	S	25.16	0.47	F 65% S 35%	
( )043	17.92	0.60	S	21.32	1.65	S	
3192-20( )037-20	31.22	1.60	S	35.66	0.87	F	
( )040	30.31	1.45	S	36.09	1.71	F	45% at Heat Strip Line 10% at Grip Line
( )043	30.98	1.09	S	33.45	1.45	S	
( )046	29.84	1.65	S	33.94	0.89	S	
3192-16( )037-20	29.09	0.77	F 15% S 85%	32.41	0.46	F	
( )040	32.27	0.79	S	33.80	0.55	F	
( )043	31.13	0.73	S	36.87	1.13	F	
( )046	31.20	0.75	S	36.80	0.59	F	
( )050				34.20	1.80	S	
3192-16( )043-16	56.44	1.96	S	66.30	2.60	F	
( )046	56.94	2.84	S	67.00	1.76	F	
( )050	55.02	2.57	S	66.70	1.41	F	
( )054	46.69	2.11	S	65.70	0.68	S	
Score, Contact Type and Configuration			S 15.75 F 0.25			S 5.35 F 11.65	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR MS TYPE 3193 CRIMPED CONTACTS AS A
FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
3193-20( )032-22				21.10	0.56	F	
( )034	23.63	1.20	S	26.62	0.45	F	33% at Grip
( )037	23.41	2.23	S	25.56	0.62	F	60% at Grip
( )040	24.49	1.35	S	25.31	0.64	F 85% S 15%	35% at Grip
( )043	23.12	2.58	S	21.74	1.56	S	
3193-20( )037-20	29.12	2.20	S	33.00	1.00	F	
( )040	25.96	2.32	S	34.29	1.02	F	
( )043	25.21	1.68	S	32.40	0.92	F	With >90% Strand Failure at Heat Strip Line
( )046	24.00	1.69	S	30.41	1.70	S	
3193-16( )037-20	29.66	0.52	F 35% S 65%	27.34	1.30	F	
( )040	29.05	1.02	S	29.56	0.53	F	
( )043	28.25	0.46	S	32.01	0.42	F	
( )046	26.65	0.68	S	32.38	0.70	F 75% S 25%	
( )050				32.84	2.39	S	
3193-16( )043-16	50.48	1.82	S	60.33	2.09	F	
( )046	51.33	2.95	S	64.58	1.98	F	
( )050	52.13	2.54	S	69.27	1.87	F 50% S 50%	
( )054	49.99	3.20	S	63.96	1.47	S	
Score, Contact Type and Configuration			S 15.65 F 0.35			S 4.90 F 13.10	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR BENDIX TYPE CE (PIN) CRIMPED CONTACTS AS
A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size	Indentor Spacing / Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
CEPI-20(	)034-22	23.20	0.85	F	23.06	0.49	F	
(	)037	23.84	0.84	F 18% Broke at Grip	24.89	0.49	F 90% S 10%	
(	)040	23.82	0.68	F 65% Broke at Grip	25.97	0.58	F 90% S 10%	40% Broke at Grip
(	)043	23.32	1.21	F 40% 10% Broke at Grip S 60%	25.57	0.78	F	30% Broke at Grip
(	)046				19.09	0.57	S	
CEPI-20(	)037-20	23.29	1.99	F	25.06	0.94	F	
(	)040	26.28	1.64	F	26.48	0.85	F	
(	)043	27.30	1.07	F 85% S 15%	31.19	0.83	F	
(	)046	26.39	0.67	F 10% S 90%	32.46	0.97	F 90% S 10%	
(	)050				32.67	1.68	S	
CEPI-16(	)037-20	24.62	1.92	F	21.10	1.06	F	
(	)040	27.65	0.69	F 82% S 18%	26.01	2.10	F	
(	)043	27.48	0.75	F 50% S 50%	33.07	0.79	F	
(	)046	27.11	0.49	F 20% S 80%	34.72	0.99	F	
(	)050				31.67	1.33	S	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR BENDIX TYPE CE (PIN) CRIMPED CONTACTS AS
A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
CEPI-16( )043-16	56.32	4.35	F 55% S 45%	51.76	2.71	F	
( )046	58.70	2.44	F 65% S 35%	57.51	3.11	F	
( )050	58.06	3.01	F 20% S 80%	63.58	2.07	F	
( )054	55.28	1.48	S	66.29	1.38	F	
( )059				64.66	1.17	S	
Score, Contact Type and Configuration			S 5.73 F 10.27			S 4.30 F 15.70	

TABLE 5 (Continued)

MECHANISM OF TENSILE FAILURE
FOR BENDIX TYPE CE (SOCKET) CRIMPED CONTACTS AS
A FUNCTION OF INDENTOR SETTING AND CONFIGURATION

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent Mean Tensile	Single Indent Std. Deviation	Single Indent Failure Mechanism	Double Indent Mean Tensile	Double Indent Std. Deviation	Double Indent Failure Mechanism	Remarks
CESO-20( )034-22	23.63	1.17	F	21.78	1.55	F	
( )037	21.03	2.19	F 50% S 50%	23.53	0.93	F	
( )040	21.05	1.13	F 20% S 80%	23.89	0.54	F 70% S 30%	
( )043	19.65	1.61	F 10% S 90%	22.10	0.77	S	
CESO-20( )037-20	27.80	2.67	F	26.85	2.98	F	
( )040	30.31	1.63	F 70% S 30%	26.79	1.79	F	
( )043	29.50	0.87	F 35% S 65%	31.33	1.58	F	
( )046	28.05	1.17	S	31.79	0.57	F 60% S 40%	
CESO-16( )037-20	25.61	1.03	F	22.42	2.71	F	
( )040	26.03	0.99	F	27.46	2.39	F	
( )043	27.15	0.91	F	29.03	1.71	F	
( )046	26.65	1.26	F 15% S 85%	23.74	0.47	F	
( )050				30.57	0.89	S	
CESO-16( )043-16	55.64	2.39	F	41.85	2.56	F	
( )046	53.36	3.47	F 65% S 35%	48.63	3.28	F	
( )050	54.77	1.82	F 85% S 15%	53.88	4.99	F 55% S 45%	
( )054	54.53	1.26	F 10% S 90%	65.68	0.88	F 85% S 15%	
( )059				62.99	1.79	S	
Score, Contact Type and Configuration			S 6.40 F 9.60			S 4.30 F 13.70	

3.5 Mechanism of Tensile Failure

The two basic mechanisms of contact tensile failure are (1) fracture of the wire and (2) slippage of the wire in the crimp barrel. The second is unique, but feacture or rupture can occur: (1) at the crimp line, (2) along the wire, e.g., the heat strip line, or (3) at the Instron grip. The entire study population of 206 specimen groups were evaluated and scored as to the mechanism of tensile failure. The tabulated results are given in table 5.

In summary, 78.5 percent of the tensile failures for the single indent configuration were wire slippages. The double indent configuration specimens had 43.3 percent slippage failures (56.7 percent fracture).

The inspection revealed the extent of wire fracture remote from the barrel crimp line. Fracture at the grip line was observed in 18 different groups with the majority being in the double indent group and groups recording tensile strength values approaching the tensile value of the stranded wire. It is significant to note that this deviation in point of fracture did not reflect any abnormal variation in the value of tensile standard deviation for the group.

A small percentage of failures were noted for strand rupture between the grips at the line where the wire was heat stripped. This was probably due to annealing of the outer strands.

A further review of these data reveals that the point of maximum double indent configuration tensile strength, as a function of indentor spacing, occurs at or adjacent to the spacing corresponding to the failure mechanism transition from fracture to slippage.

These data also give support to the hypothesis that maximum tensile strength as a function of indentor spacing corresponds to minimum standard deviation. This hypothesis cannot be accepted when the indentor spacing is decreased sufficiently to reduce the cross section of the wire at the crimp line and thereby form a uniform cross section subject to fracture with a minimum of variability. Figure 5 is a section view of a CESO-16-DO43-16 crimped contact in which failure occurred at the crimp line. The failure line is very straight. The single indent contact CESO-16-SO43-16 fractured with an uneven line, figure 6.

The maximum mean tensile strengths of a crimped connection recorded for the three wire sizes approached or exceeded the mean value of tensile strength for that wire size as given in section 3.2 This condition is more pronounced for the double

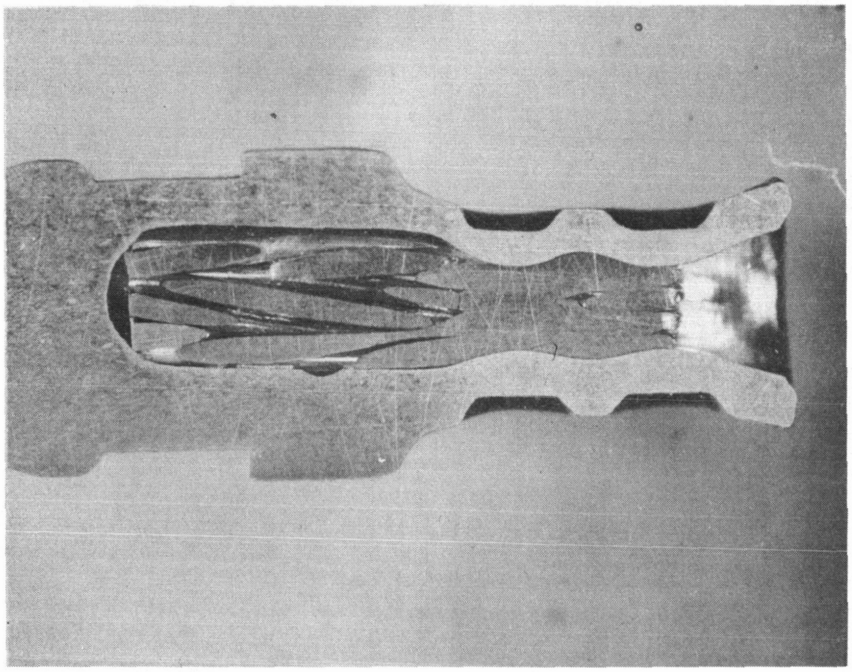


Figure 5. CESO-16-DO43-16 Section View of Crimped Contact After Tensile Test

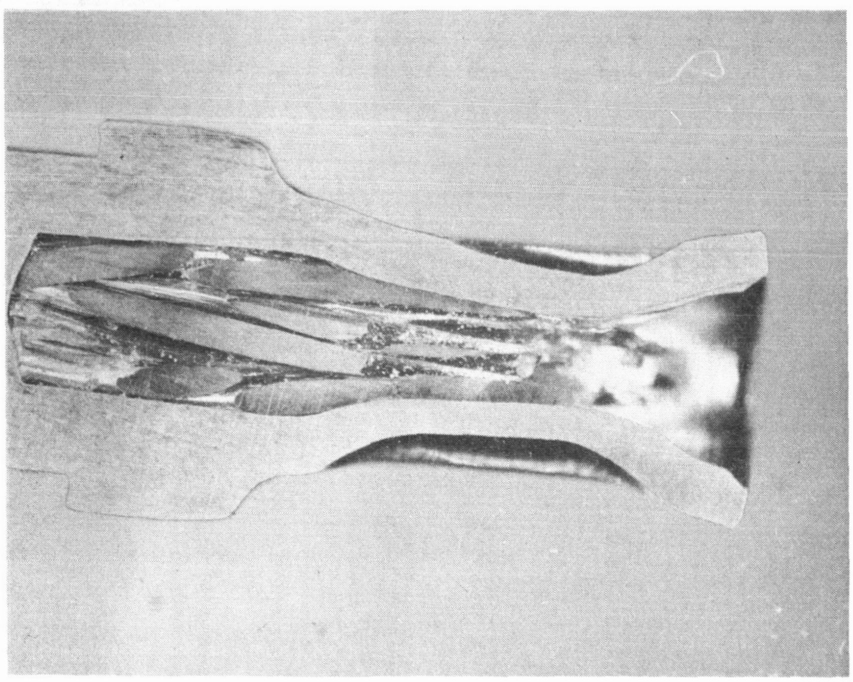


Figure 6. CESO-16-SO43-16 Section View of Crimped Contact After Tensile Test

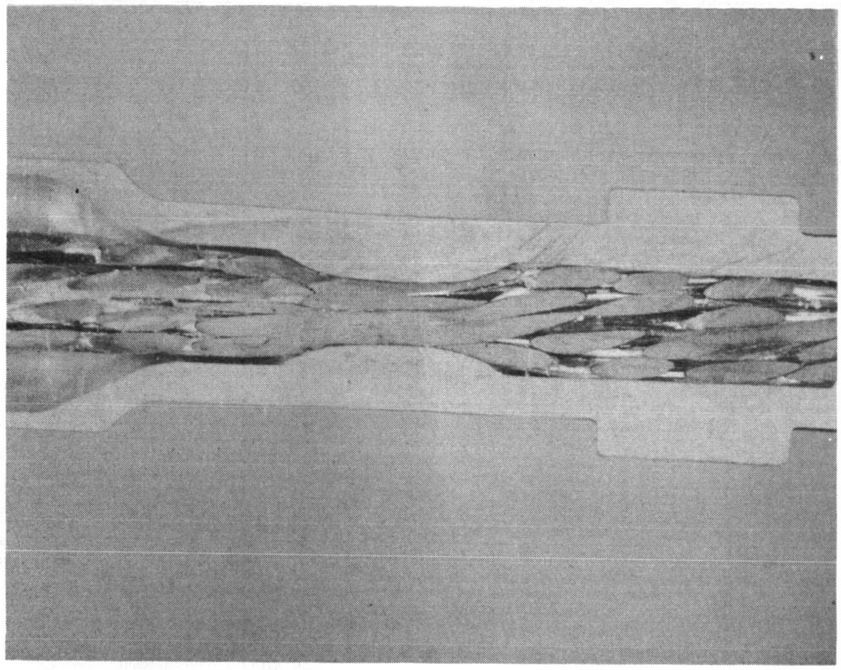


Figure 7. CESO-20-SO46-20 Section View of Crimped Contact

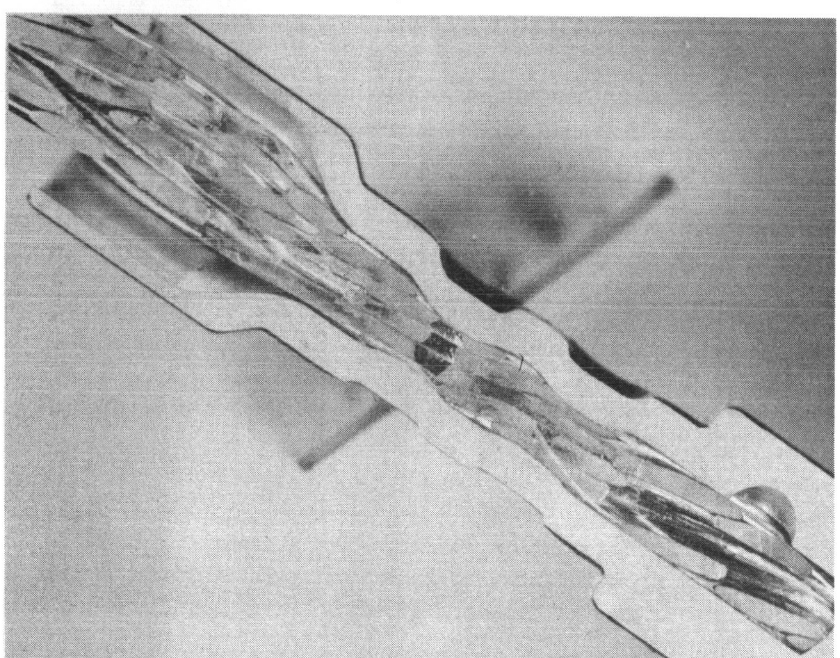


Figure 8. CESO-20-DO46-20 Section View of Crimped Contact

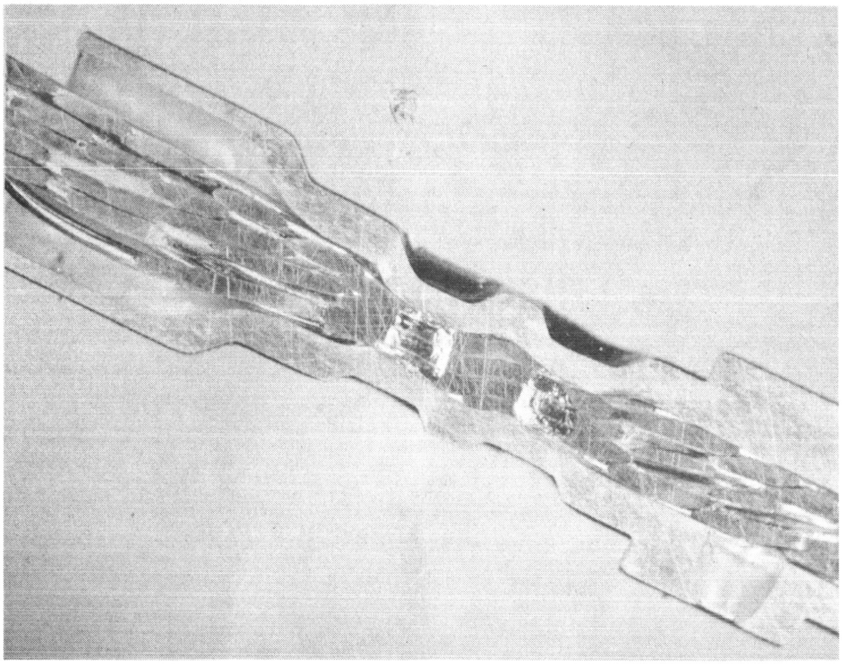


Figure 9. CESO-20-DO37-20 Section View of Crimped Contact

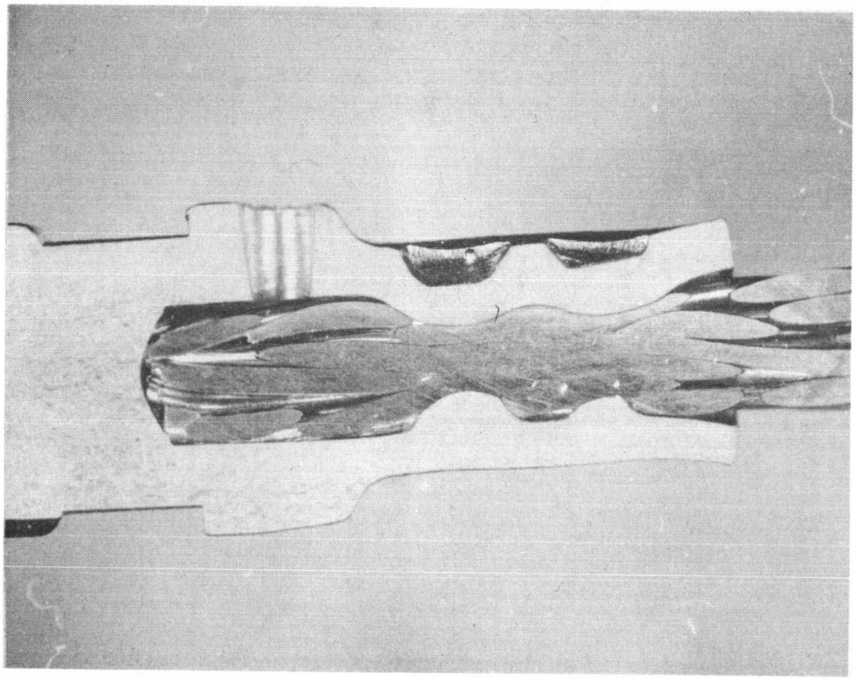


Figure 10. CESO-16-DO54-16 Crimped Contact, Sectioned View

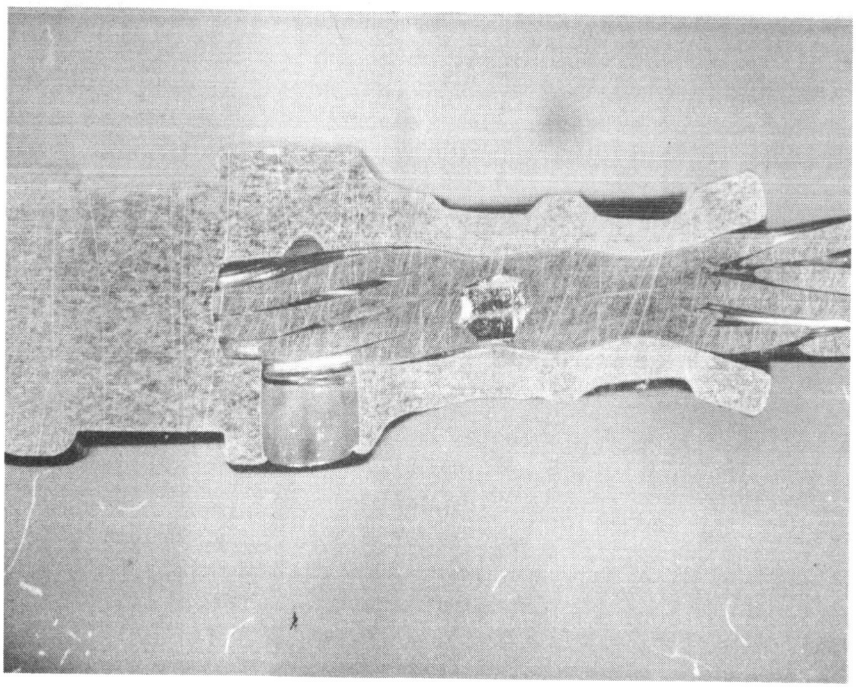


Figure 11. CESO-16-DO50-16 Crimped Contact Sectioned View

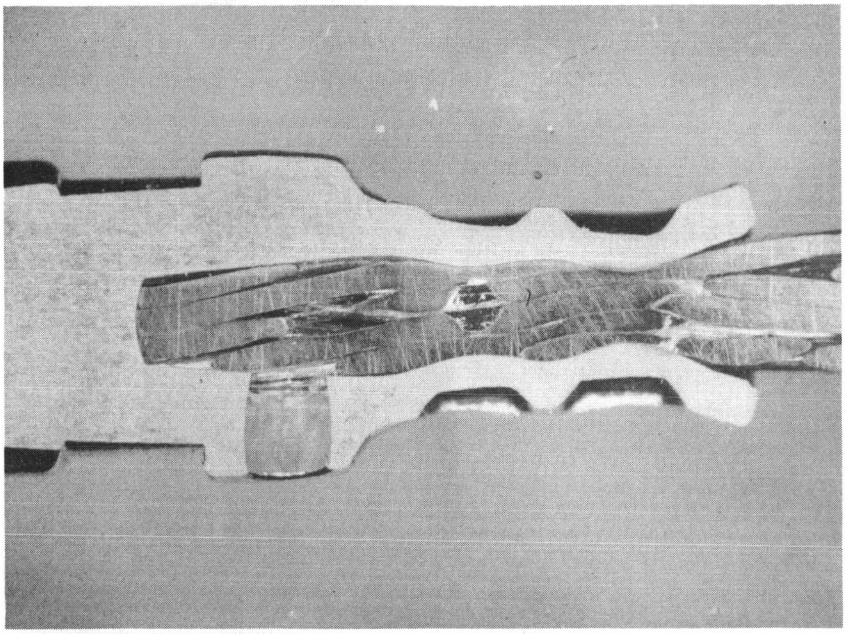


Figure 12. CESO-16-DO46-16 Crimped Contact Sectioned View

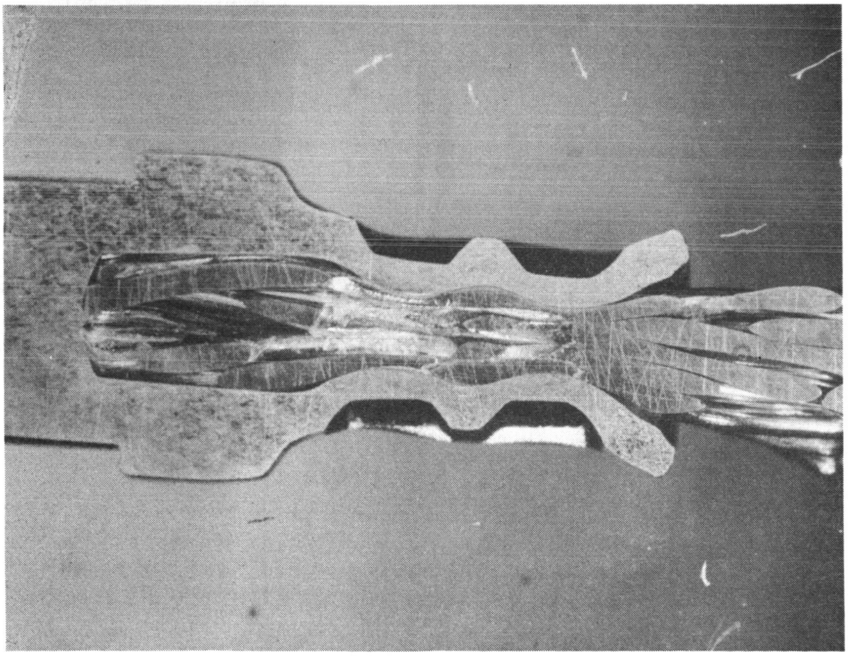


Figure 13. CESO-16-DO43-16 Crimped Contact Sectioned View

indent configuration. The double indent configuration appears to gain this improvement from its multi-point, more uniform compression of the wire strands without degrading deformation. This can be seen from the sectioned views of corresponding single and double indent crimped contacts. Figure 7 is a section view of CESO-20-SO46-20 crimped contact, and figure 8 is a section view of CESO-20-DO46-20 crimped contact. The effect of decreasing the indentor spacing for the double indent configuration does reduce the cross section of the wire. This can be seen in figure 9, a section view of a CESO-20-DO37-20 crimped contact.

The fracture mechanism of tensile failure was investigated based upon the hypothesis that the smaller indentor spacer settings, such as CESO-16-DO43-16, produced cracking of the wire strands resulting in lower tensile strength. This investigation took the form of metallographic inspection of mounted and sectioned crimped specimens.

Figure 10 is a sectioned view of a CESO-16-DO54-16 crimped specimen; figure 11 a CESO-16-DO50-16 crimped specimen; figure 12 a CESO-16-DO46-16 crimped specimen; and figure 13 a CESO-16-DO43-16 crimped specimen. The four views do indicate increased pressure as a function of decreased indentor spacing. A closer (greater magnification) inspection of the specimens did not reveal any surface cracks on any wire strands visible. All areas which appeared to be right angle breaks also had the double line feature of surface plating. If a crack had been produced by crimping, the plating would not be continuous.

3.6 Hybrid Group Investigation

Tensile strength of crimped connections is primarily a function of the wire size, material and finish, and the contact type and size with the indentor setting optimized against these. In this investigation, four indentor settings were specified for each of the wire sizes. It would be expected that tensile strength across these groups of four, i.e., tensile strength as a function of indentor spacing only, would vary smoothly. This was not found to be the case. The processed, tensile-strength-only data for 30 percent of the specimens from the 184 groups revealed unevenness. This can be seen in the tensile strength plots of figure 14 through 19.

A review of the experiment and its controls pointed to the possibility of variability in wire used within the groups of four. This possibility was rather certain due to the inability to obtain the required wire from a single source. In an attempt to confirm this, hybrid experiment groups were prepared. The experiment specified the use of wire stamped for one indentor spacing in a group of four for the preparation of specimens with the indentor spacing of the group considered out of line.

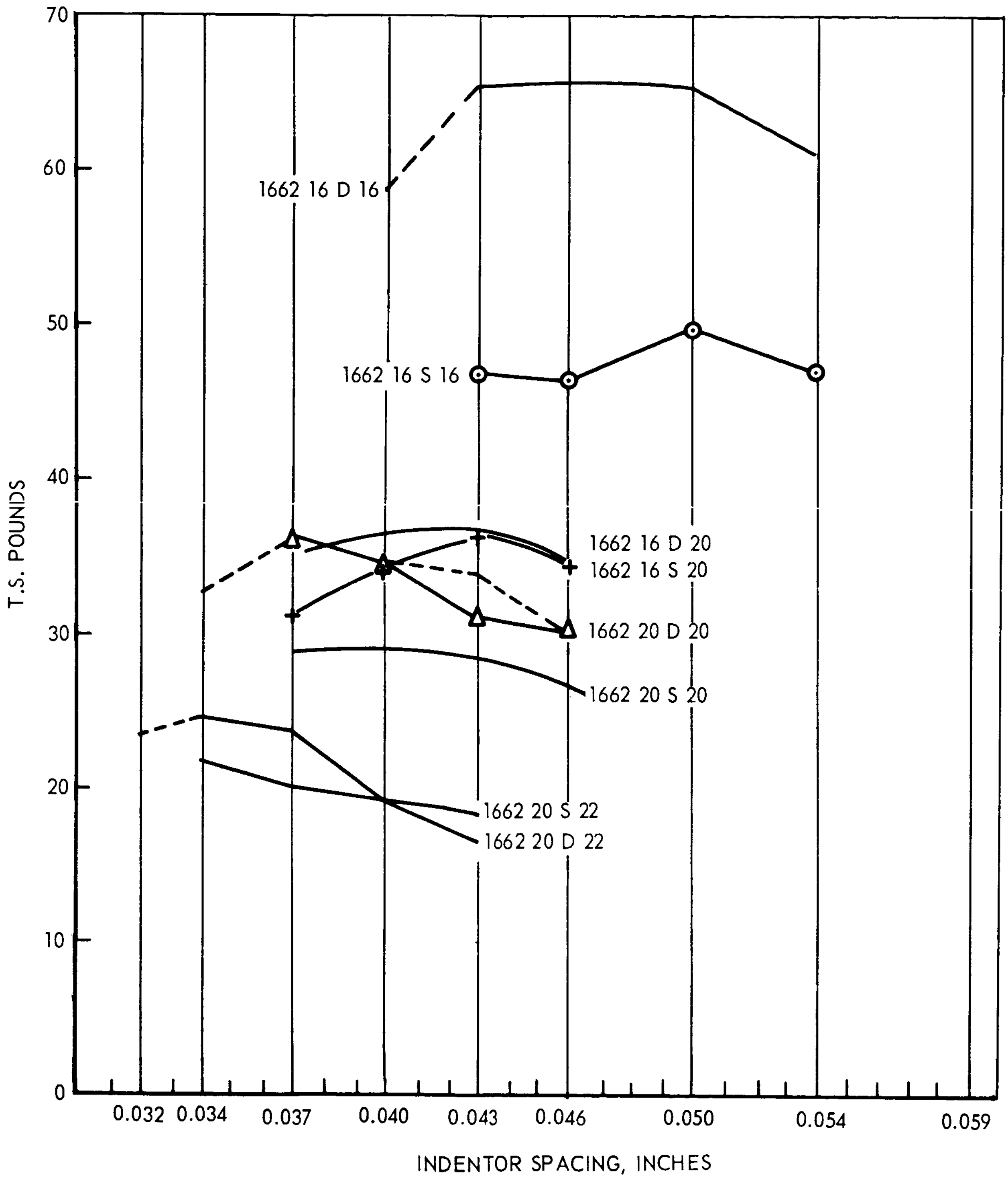


Figure 14. Tensile Strength vs. Indentor Spacing - NAS 1662 Contacts and Nickel Plated Wire

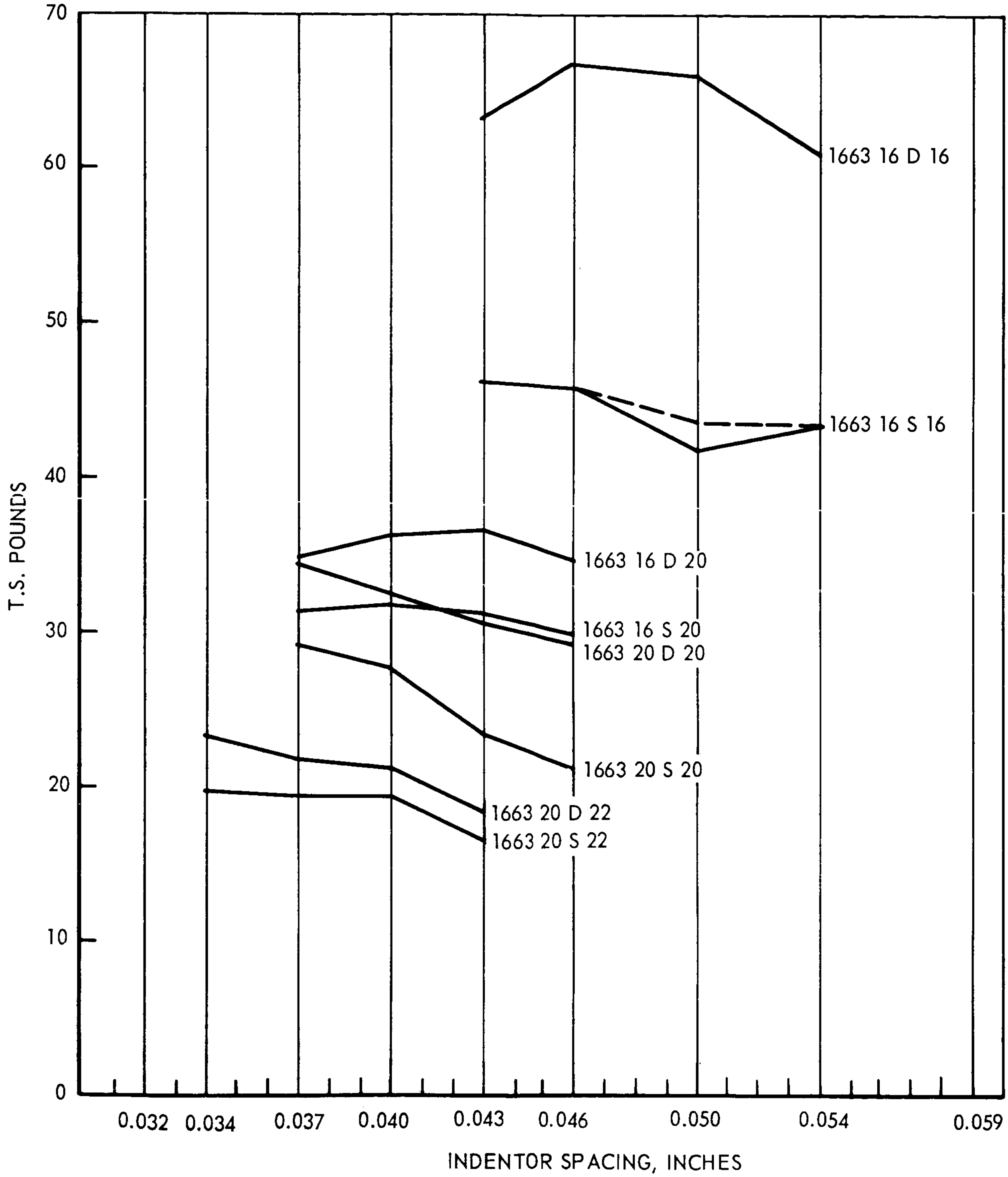


Figure 15. Tensile Strength vs. Indentor Spacing - NAS 1663 Contacts and Nickel Plated Wire

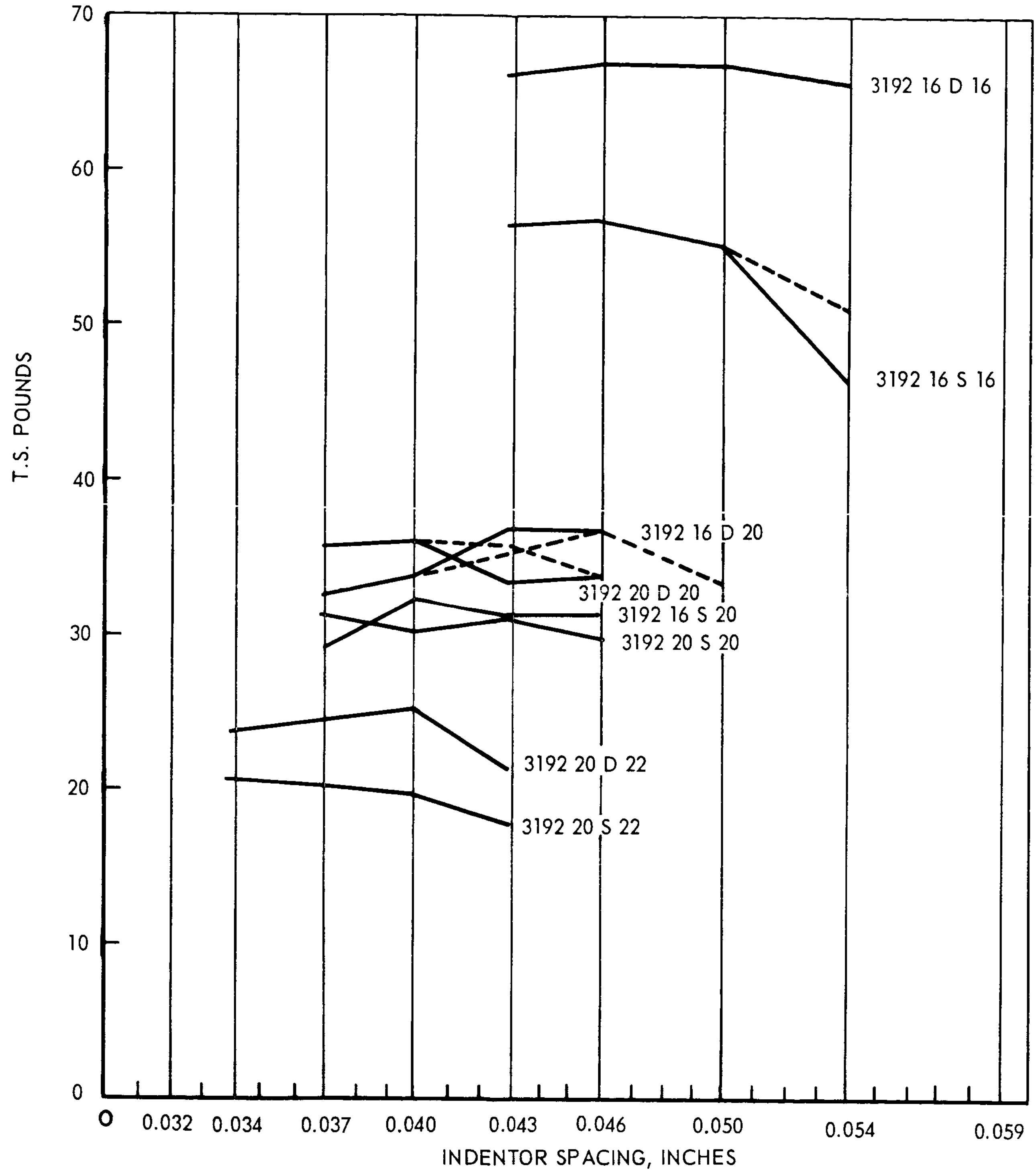


Figure 16. Tensile Strength vs. Indentor Spacing - MS 3192 Contacts and Nickel Plated Wire

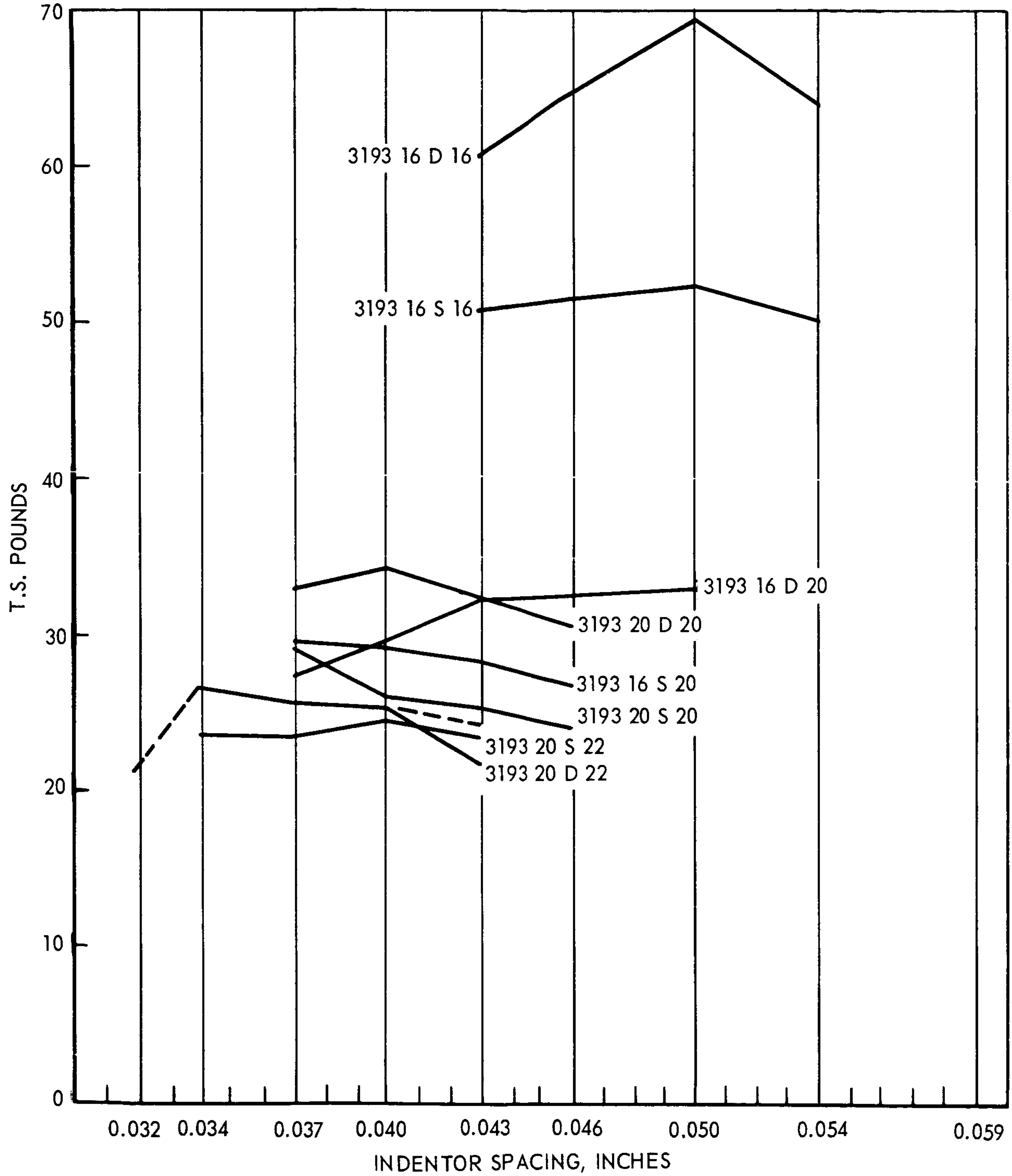


Figure 17. Tensile Strength vs. Indentor Spacing - MS 3193 Contacts and Nickel Plated Wire

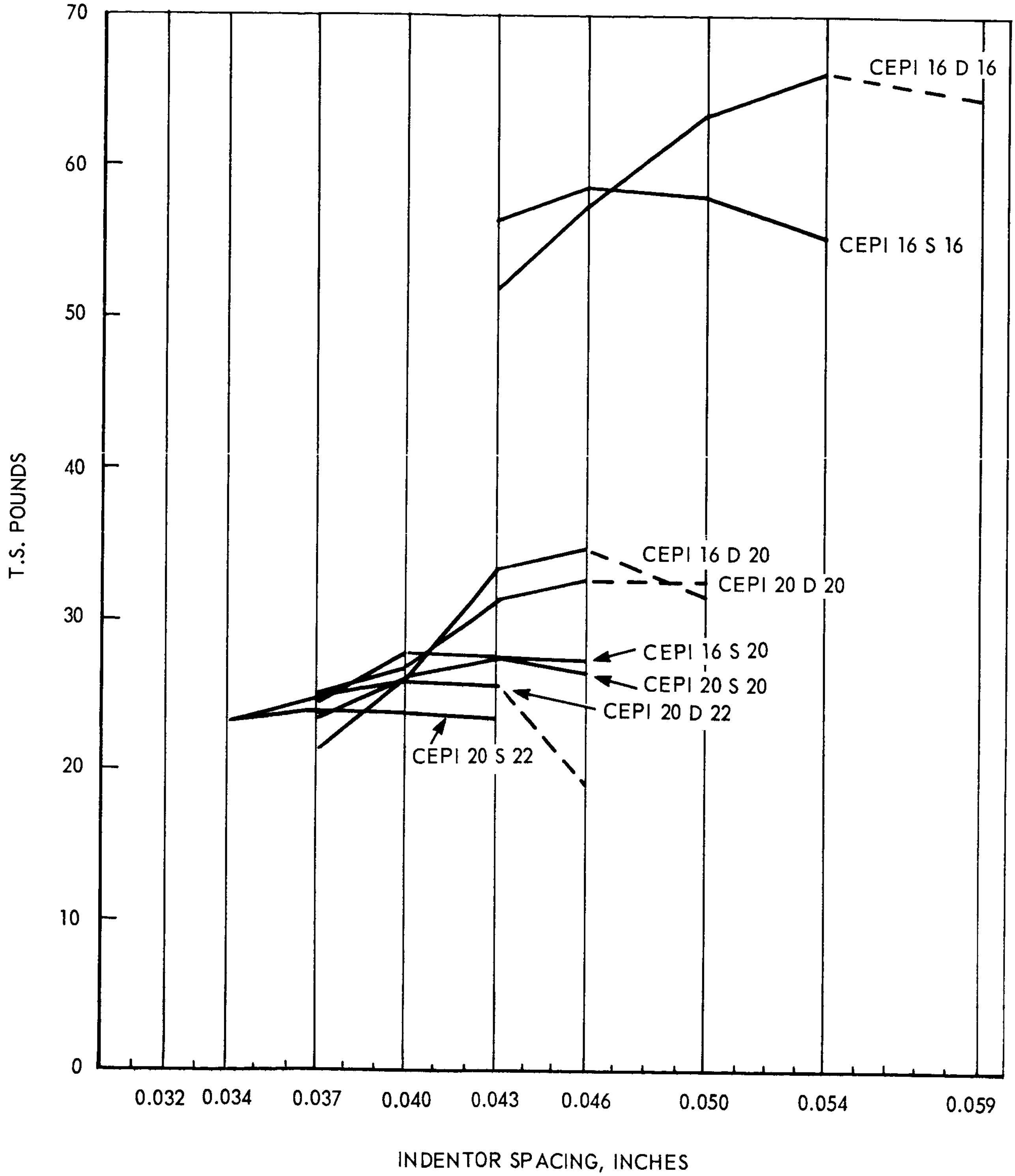


Figure 18. Tensile Strength vs. Indentor Spacing - Bendix CE Pin Contacts and Nickel Plated Wire

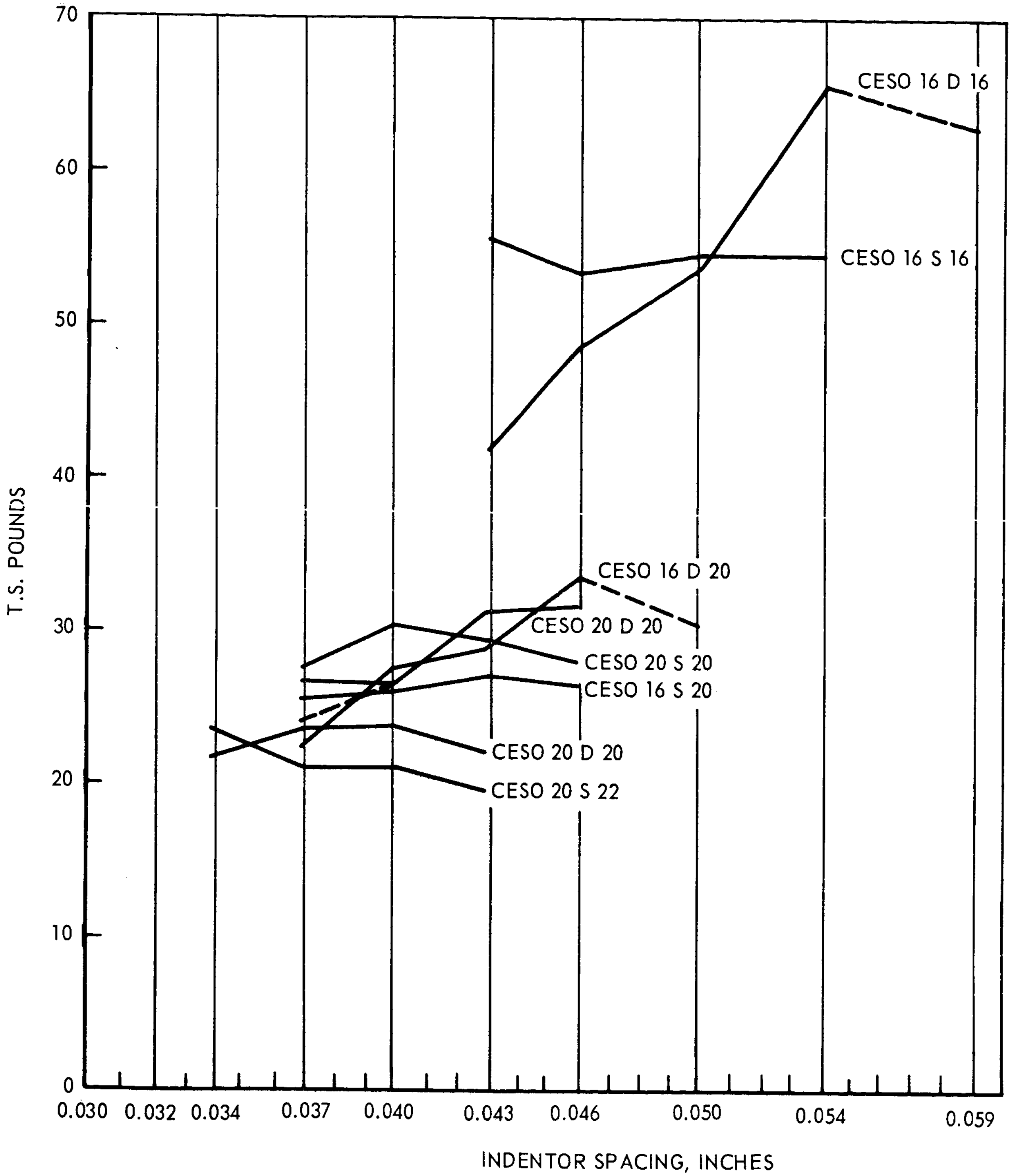


Figure 19. Tensile Strength vs. Indentor Spacing - Bendix CE Socket Contacts and Nickel Plated Wire

TABLE 6

TENSILE STRENGTH VARIATIONS
AS A FUNCTION OF DIFFERENT WIRE

POUNDS

Contact Type	Contact Size	Indentor Spacing	Wire Size	Original Mean Tensile Strength	Original Std. Deviation		Hybrid Mean Tensile Strength	Hybrid Std. Deviation
1662	20	D037	20	36.12	0.40			
		040		35.73	0.78			
		043		30.97	0.76		33.90	0.43
		046		30.08	0.68			
1662	16	S037	20	31.10	3.33		35.70	2.83
		040		34.89	1.49			
		043		36.18	2.15			
		046		34.44	1.96			
1662	16	D043	16	65.21	1.75			
		046		65.67	1.62			
		050		65.28	1.24			
		054		60.96	1.21		60.69	2.85
1663	20	S034	22	19.84	0.64			
		037		19.45	0.96			
		040		19.41	0.79			
		043		16.73	0.90		17.01	0.78
1663	16	S043	16	46.13	3.27			
		046		45.79	3.23			
		050		41.80	2.58		43.63	2.44
		054		43.28	4.06			
3192	20	D034	22	23.82	0.29			
		037		24.67	1.18			
		040		25.16	0.47			
		043		21.32	1.65		20.69	1.04
3192	20	D037	20	35.66	0.87			
		040		36.09	1.71			
		043		33.45	1.45		35.76	0.70
		046		33.94	0.89			
3192	16	D037	20	32.41	0.46			
		040		33.80	0.55			
		043		36.87	1.13		35.62	0.50
		046		36.80	0.59			

TABLE 6 (Continued)

TENSILE STRENGTH VARIATIONS
AS A FUNCTION OF DIFFERENT WIRE

POUNDS

Contact Type	Contact Size	Indentor Spacing	Wire Size	Original Mean Tensile Strength	Original Std. Deviation		Hybrid Mean Tensile Strength	Hybrid Std. Deviation
3192	16	S043	16	56.44	1.96			
		046		56.94	2.84			
		050		55.02	2.57			
		054		46.69	2.11		50.95	2.11
3193	20	D034	22	26.62	0.45			
		037		25.56	0.62			
		040		25.31	0.64			
		043		21.74	1.56		24.30	1.15
3193	20	S037	22	29.12	2.20		28.89	1.66
		040		25.96	2.32			
		043		25.21	1.68			
		047		24.00	1.69			
CEPI	20	S037	20	23.29	1.99		24.89	1.31
		040		26.28	1.64			
		043		27.30	1.07			
		046		26.39	0.67			
CEPI	16	S037	20	24.62	1.92		25.84	1.12
		040		27.65	0.69			
		043		27.48	0.75			
		046		27.11	0.49			
CEPI	16	D037	20	21.10	1.06		24.73	1.35
		040		26.01	2.10			
		043		33.07	0.79			
		046		34.72	0.99			
CESD	20	D037	20	26.85	2.98		24.09	2.38
		040		26.79	1.79			
		043		31.33	1.58			
		046		31.79	0.57			

For example, a sample lot was prepared conforming to the requirements of 1662-20-D043-20 with wire stamped 1662-20-D040-20. The tensile strength of the hybrid lot was 33.90 pounds. This increase of 2.92 pounds is plotted in figure 14. A total of 15 hybrid lots were prepared and tensile tested. The results are given in Table 6. These data indicate 12 incidents of improvements, two incidents of no significant change, and one incident of degradation. Of the 15, a number have been plotted with dotted lines in figures 14 through 19.

From the plots of the specified lots, figures 14 through 19, there were indications that the specified range of indentor spacings was not sufficient to bracket the optimum or maximum tensile strength setting. A second supplementary grouping was prepared. The indentor spacing was such as to increase certain of the groups of four to groups of five. This data is listed as Serial 200 in the data file. The results of this investigation are included in table 4 and plotted in figures 14 through 19.

The results of these experiments confirmed that wires from different sources vary sufficiently to cause very noticeable changes in tensile strength, and the range of indentor settings should be expanded by a factor of 1.5 both in number and setting spread. In the case of the CE contacts, the median value for the double indent crimp should be 0.003 inch greater than the median value of the single indent crimp for the same contact and wire size.

3.7 Environmental Stress

The effects of the environmental exposure of the crimped contacts on tensile strength is given in table 7. The mean tensile values, designated TAB, correspond to 50 percent of the fabricated specimens, i.e., all that were not exposed to any environmental stress; TE corresponds to 38 percent of the specimens which were exposed to the environmental stresses of shock, vibration, thermal shock, and life test, but not salt fog; and TS corresponds to 12 percent of the specimens which were exposed to all environmental stresses including salt fog.

A review of the mean values indicates that the environmental stress did not significantly affect the tensile strength of the crimped contact assemblies. Small values of decrease are noted (5 to 10 percent) for the TE data. The salt fog TS data reveals general increases in tensile strength for the single indent specimens and decrease in tensile strength for the double indent configuration specimens.

It can be conjectured that the heat cycling and heat storage yielded a slight reduction in compression forces on the wire due to differential expansion and elasticity of the wire and contact barrel. The salt fog and its associated corrosive action increased the coefficient of friction between the wire and the contact barrel and thereby increased tensile for those contact assemblies which fail due to slippage. For those assemblies which are crimped at spacings which constitute a reduction in the effective cross section of the wire, tensile strength reductions up to 24 percent were recorded for other 16D043-16 groups but not to the same extent.

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7

AVERAGE TENSILE STRENGTH OF NAS TYPE 1662 CONTACTS
CRIMPED TO NICKEL PLATED COPPER WIRE AS
A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR
CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent					Double Indent				
	TAB	TE	TS	15 TS > TAB	1 TS < TAB	TAB	TE	TS	8 TS > TAB	8 TS < TAB
1662-20( )034-22	21.75	21.98	23.86	+		24.33	24.65	22.77		-
( )037	19.01	19.05	19.78	+		23.53	23.46	23.52		-
( )040	19.14	19.96	22.96	+		18.98	19.24	19.38	+	
( )043	17.96	18.35	22.57	+		16.97	16.42	17.47	+	
1662-20( )037-20	28.66	28.53	33.52	+		35.89	35.28	35.48		-
( )040	28.75	31.27	36.48	+		35.07	35.10	36.38	+	
( )043	27.82	29.49	35.43	+		30.88	31.11	33.82	+	
( )046	25.76	26.47	30.94	+		29.56	28.85	32.55	+	
1662-16( )051-20	31.27	31.69	33.33	+		35.54	33.79	33.42		-
( )040	34.80	34.88	34.72		-	35.69	34.89	34.67		-
( )043	34.39	33.62	34.84	+		36.47	35.82	35.57		-
( )046	34.20	33.62	34.78	+		34.44	34.51	35.53	+	
1662-16( )043-16	47.46	49.70	59.61	+		64.66	61.44	61.31		-
( )046	46.33	47.39	52.84	+		65.06	63.45	63.47		-
( )050	49.56	49.55	56.85	+		63.98	62.24	64.76	+	
( )054	47.02	46.99	57.67	+		60.21	59.59	64.12	+	

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7 (Continued)

AVERAGE TENSILE STRENGTH OF NAS TYPE 1663 CONTACTS
CRIMPED TO NICKEL PLATED COPPER WIRE AS
A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR
CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent			16 TS > TAB	0 TS < TAB	Double Indent			8 TS > TAB	8 TS < TAB
	TAB	TE	TS			TAB	TE	TS		
1663-20( )034-22	19.47	20.79	21.24	+		22.91	22.91	22.14		-
( )037	19.48	20.08	19.92	+		21.87	21.59	21.94	+	
( )040	19.21	19.44	19.78	+		21.06	20.35	20.93		-
( )043	16.20	16.80	19.73	+		18.50	18.46	19.53	+	
1663-20( )037-20	28.85	30.14	35.47	+		34.35	33.92	33.52		-
( )040	27.45	28.34	34.52	+		32.59	32.19	32.49		-
( )043	23.07	24.11	24.71	+		30.54	31.20	32.95	+	
( )046	20.89	21.63	22.90	+		28.86	28.10	30.43	+	
1663-16( )037-20	30.89	30.43	33.02	+		34.47	30.31	30.97		-
( )040	31.72	31.10	33.18	+		35.63	35.46	33.47		-
( )043	31.26	30.91	35.30	+		36.14	35.83	35.07		-
( )046	30.03	29.83	33.84	+		34.82	34.89	35.52	+	
1663-16( )043-16	46.21	48.03	58.91	+		63.22	61.61	64.05	+	
( )046	44.71	45.21	46.82	+		66.76	65.28	65.09		-
( )050	44.15	44.94	63.19	+		65.73	63.63	68.57	+	
( )054	43.29	44.54	63.38	+		60.31	57.60	63.60	+	

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7 (Continued)

AVERAGE TENSILE STRENGTH OF MS TYPE 3192 CONTACTS
CRIMPED TO NICKEL PLATED COPPER WIRE AS
A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR
CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent					Double Indent				
	TAB	TE	TS	13 TS > TAB	3 TS < TAB	TAB	TE	TS	4 TS > TAB	12 TS < TAB
3192-20( )034-22	20.59	20.68	21.29	+		23.73	21.98	22.05		-
( )037	19.99	20.12	21.45	+		24.38	24.25	23.26		-
( )040	19.42	19.37	20.41	+		24.49	25.46	24.93	+	
( )043	17.79	18.36	19.37	+		21.44	21.73	21.35		-
3192-20( )037-20	31.63	32.27	33.19	+		35.53	34.21	32.57		-
( )040	30.77	31.96	33.97	+		35.72	35.54	34.03		-
( )043	31.18	32.12	35.21	+		33.69	34.10	34.62	+	
( )046	30.43	30.53	33.78	+		34.06	34.26	34.79	+	
3192-16( )037-20	29.00	28.98	28.64		-	31.85	28.30	25.96		-
( )040	32.32	33.24	31.62		-	33.24	30.62	30.21		-
( )043	30.97	32.10	32.31	+		36.14	34.41	32.44		-
( )046	30.58	31.56	32.77	+		36.51	36.43	34.63		-
3192-16( )043-16	54.79	54.63	54.70		-	65.92	49.87	49.92		-
( )046	56.36	57.36	64.46	+		66.02	52.22	55.24		-
( )050	52.54	50.35	55.89	+		66.53	66.37	65.35		-
( )054	46.25	48.26	56.22	+		65.40	65.33	69.26	+	

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7 (Continued)

AVERAGE TENSILE STRENGTH OF MS TYPE 3193 CONTACTS
CRIMPED TO NICKEL PLATED COPPER WIRE AS
A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR
CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent			12 TS > TAB	4 TS < TAB	Double Indent			1 TS > TAB	15 TS < TAB
	TAB	TE	TS			TAB	TE	TS		
3193-20( )034-22	23.41	24.00	24.28	+		28.56	26.69	24.12		-
( )037	23.62	24.12	23.82	+		24.97	25.61	23.64		-
( )040	24.42	24.02	23.32		-	24.91	25.02	23.32		-
( )043	22.53	22.17	21.00		-	21.72	20.34	21.44		-
3193-20( )037-20	28.83	28.61	34.82	+		32.81	31.25	30.67		-
( )040	25.45	26.73	30.45	+		33.70	33.39	32.72		-
( )043	24.67	25.59	32.77	+		31.87	33.18	31.62		-
( )046	24.00	24.47	27.32	+		29.97	31.06	31.26		-
3193-16( )037-20	29.40	29.24	29.36		-	27.10	24.86	23.87		-
( )040	28.88	29.02	29.75	+		29.65	29.15	28.22		-
( )043	28.02	28.83	28.00		-	31.96	31.72	30.35		-
( )046	26.34	26.89	27.89	+		32.13	32.42	31.63		-
3193-16( )043-16	50.45	50.15	61.30	+		60.05	58.50	58.54		-
( )046	51.45	54.46	64.34	+		64.15	63.25	63.17		-
( )050	51.79	52.94	58.54	+		68.80	66.06	65.90		-
( )054	49.30	49.96	59.82	+		63.87	65.62	68.00	+	

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7 (Continued)

AVERAGE TENSILE STRENGTH OF BENDIX TYPE CE (PIN)
CONTACTS CRIMPED TO NICKEL PLATED COPPER WIRE AS
A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR
CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent TAB	Single Indent TE	Single Indent TS	8 TS > TAB	8 TS < TAB	Double Indent TAB	Double Indent TE	Double Indent TS	3 TS > TAB	13 TS < TAB
CEPI-20( )034-22	23.20	23.07	23.04		-	22.92	25.32	21.87		-
( )037	23.54	23.47	23.31		-	24.59	27.03	24.02		-
( )040	23.74	23.53	24.11	+		25.74	28.50	25.17		-
( )043	22.96	21.07	23.60	+		24.64	27.25	25.21	+	
CEPI-20( )037-20	23.51	21.20	22.62		-	24.55	21.78	23.36		-
( )040	26.49	23.49	25.19		-	26.49	24.82	25.45		-
( )043	27.43	26.23	28.03	+		30.60	28.77	30.59		-
( )046	26.45	26.03	28.06	+		32.12	30.75	32.54	+	
CEPI-16( )037-20	24.54	21.43	22.96		-	20.79	18.85	18.82		-
( )040	27.50	25.86	26.67		-	25.92	22.75	23.65		-
( )043	27.12	25.29	28.06	+		32.99	30.15	30.97		-
( )046	26.88	25.39	27.79	+		34.64	31.37	32.68		-
CEPI-16( )043-16	56.57	51.92	48.05		-	51.33	46.31	48.62		-
( )046	57.97	53.02	54.42		-	56.30	51.06	52.94		-
( )050	57.87	55.76	57.88	+		62.53	56.99	59.01		-
( )054	54.74	52.45	60.05	+		66.00	64.41	66.87	+	

TAB - Average Tensile Strength of 50 unstressed sample specimens.

TE - Average Tensile Strength of 38 thermally and mechanically shocked and life tested sample specimens.

TS - Average Tensile Strength of 12 thermally and mechanically shocked, life tested, and salt fog exposed sample specimens.

TABLE 7 (Continued)

AVERAGE TENSILE STRENGTH OF BENDIX TYPE CE (SOCKET) CONTACTS CRIMPED TO NICKEL PLATED COPPER WIRE AS A FUNCTION OF CONTACT SIZE, INDENTOR SPACING, INDENTOR CONFIGURATION, WIRE SIZE, AND ENVIRONMENTAL EXPOSURE

POUNDS

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent					Double Indent				
	TAB	TE	TS	4 TS > TAB	8 TS < TAB	TAB	TE	TS	3 TS > TAB	9 TS < TAB
CESO-20( )034-22	23.66	22.66	22.28		-	21.66	20.35	20.13		-
( )037	21.36	23.24	22.07	+		23.62	22.71	22.49		-
( )040	20.71	21.27	21.45	+		23.39	24.19	23.84	+	
( )043	19.13	20.34	20.71	+		22.52	22.12	23.07	+	
CESO-20( )037-20	27.27	20.09	19.07		-	26.18	23.24	24.52		-
( )040	29.93	25.56	26.80		-	26.55	23.02	24.52		-
( )043	29.62	28.81	28.01		-	31.21	30.40	29.99		-
( )046	27.57	28.78	28.67	+		31.73	32.25	32.01	+	
CESO-16( )037-20	25.60	X	X			22.34	X	X		
( )040	25.99	X	X			27.37	X	X		
( )043	27.18	X	X			29.06	X	X		
( )046	26.66	X	X			33.44	X	X		
CESO-16( )043-10	55.30	47.20	49.96		-	41.74	37.30	37.25		-
( )046	52.50	48.88	50.88		-	47.99	45.34	45.51		-
( )050	54.57	52.30	52.05		-	53.92	49.43	50.29		-
( )054	54.88	54.36	53.45		-	64.30	61.58	61.32		-

4. VOLTAGE DROP

4.1 General

Voltage drop, as a function of a prescribed current, is the normally accepted means of indicating electrical quality of crimped connections. The technical guide lines given in the Foreword of the report specified two such measurements. The first immediately after crimping and the second after environmental exposure. The contract was amended to allow the environmentally exposed specimens to be further exposed to the corrosive atmosphere of 1/2 percent salt fog. The specimens were again inspected for voltage drop after the salt fog exposure.

The voltage drop measured, in general, exceeded the value specified in MIL-T-22520. This was observed for all three sets of voltage-drop measurements. It was also observed that the voltage drop increased after the environmental exposure and, to a greater extent, after the salt fog exposure.

4.2 Measurement Procedure

The applicable specification delineates voltage drop as being that voltage measured from the flared end of the crimp barrel and a point on the wire 0.5 inch from the crimp line when the wire and crimp joint are carrying a specified current. The voltage drop limits for the contact and wire sizes of this study are tabulated here for reference:

Contact Size	Wire Size	Amperes	M.V. Drop
20	22	5.0	4.0
20	20	7.5	4.0
16	20	7.5	4.0
16	16	13.0	3.5

The specimens were mounted in three inspection clips which provided electrical connection for the test current and the voltage drop connection to the stripped wire. The voltage drop connection to the contact shoulder was made with an alligator clip. The current source was a spot-calibrated, unregulated power supply, with a series isolation resistor of approximately 1.5 ohms. The voltage drop was measured by a calibrated millivolt meter. The 1/2 inch distance was maintained with the piece of insulation heat stripped for that purpose; see figure 2.

It is recognized that the method of voltage drop measurement has the limitations of including a portion of the excitation current circuit in the voltage circuit. A true Kelvin Bridge-type measurement could only be obtained if the end of wire at the bottom of the contact barrel was made one of the points of voltage pickup. This would be feasible if the wire end did not touch the contact and an insulated probe were used through the inspection hole. The prescribed 1/2 inch spacing of the pickup contact yields voltage drop values that generally exceed the limit values given above. This was observed for both nickel- and silver-plated wire. In fact, 1/2 inch of AWG 22 bare solid copper wire has a voltage drop of just less than 4.0 millivolts.

The voltage drop data recorded and presented in this report and other print outs is the voltage drop of 1/2 inch of wire and the crimp. The 1/2 inch distance was maintained uniform throughout all measurements by the use of the stripped insulation spaces.

4.3 Crimp Configuration

The measured mean voltage drop for the 192 different contact, wire, configuration and depth combinations is given in appendix D. A review of the initial values reveals no significant differences in voltage drop as a function of indent depth or configuration.

4.4 Environmental Stress

The voltage drop data recorded after the initial environmental and salt fog tests is also presented in appendix D. For ease of comparison, the 46 contact types, contact sizes, wire sizes, and indent configuration combination averages are presented in table 8. From these data it can be concluded that the voltage drop increased after the temperature and vibration test.

The data reveals even greater increases in voltage drop at the conclusion of the salt fog exposure. The magnitude of increase is greatest in the NAS and MS groups. The increases in the CE groups were less than 25 percent. This anomaly has not been explained.

Table 8 scores the single indent configuration against the double indent configuration groups. The single indent configuration groups had higher average voltage drop at the conclusion of the salt fog stress exposure in 19 out of 23 comparisons. These data follow closely the tensile data as analyzed in section 3.7. The conclusions made about relative tensile strength can be made about relative voltage drop after salt fog exposure, i.e.:

a. The double indent configuration yields lower voltage drop after salt spray for the entire population studied.

b. There was no significant difference for the CE group when considered alone.

"B" - Data from 24 sample specimens from each group as prepared.

"E" - Data from 12 sample specimens from each group after thermal and mechanical shock and life test.

"S" - Data from the 12 "E" sample specimens after 10 days of 1/2 percent salt fog at $50^{\circ}C$.

"SIVDS" - Single Indent Voltage Drop - S

"DIVDS" - Double Indent Voltage Drop - S

TABLE 8

AVERAGE VOLTAGE DROP OF COMBINED GROUPS OF CRIMPED CONTACTS, FOR CONTACT TYPE, CONTACT SIZE, AND WIRE SIZE AS A FUNCTION OF ENVIRONMENTAL STRESS AND INDENT CONFIGURATION

Contact Type - Contact Size - Wire Size	Single Indent Voltage Drop			SIVDS > DIVDS	Double Indent Voltage Drop			DIVDS > SIVDS
	B	E	S		B	E	S	
1662-20-22Avg	5.9	7.8	12.9	+	7.0	7.6	10.0	
1662-20-20Avg	6.5	8.9	18.0	+	5.4	5.4	9.0	
1662-16-20Avg	7.3	10.9	24.6	+	5.2	5.7	9.4	
1662-16-16Avg	8.1	10.3	18.9	+	4.6	5.8	8.4	
1663-20-22Avg	6.5	7.7	17.8	+	6.3	6.7	13.0	
1663-20-20Avg	7.1	10.5	25.6	+	6.2	6.8	19.0	
1663-16-20Avg	5.7	7.6	12.0	+	5.1	5.8	9.5	
1663-16-16Avg	8.2	11.5	18.5	+	4.5	6.5	7.4	
3192-20-22Avg	6.4	7.0	7.8		6.4	7.4	8.6	+
3192-20-20Avg	6.2	9.8	20.4	+	5.9	6.5	10.4	
3192-16-20Avg	6.3	7.6	11.9	+	4.8	5.2	11.6	
3192-16-16Avg	7.5	9.9	12.9	+	4.5	5.9	6.7	
3193-20-22Avg	5.6	7.5	8.9	+	5.8	6.8	8.3	
3193-20-20Avg	7.2	9.2	12.0	+	6.2	7.0	7.7	
3193-16-20Avg	5.6	6.5	6.6	+	5.1	5.4	5.6	
3193-16-16Avg	6.1	8.3	11.5	+	4.1	5.2	5.9	
CEPI-20-22Avg	4.5	5.3	5.4		5.4	6.4	5.7	+
CEPI-20-20Avg	5.3	5.7	5.1		5.9	6.1	5.4	+
CEPI-16-20Avg	6.0	6.4	6.6	+	5.6	5.4	5.6	
CEPI-16-16Avg	4.6	4.8	6.5	+	4.1	3.7	4.4	
CESO-20-22Avg	5.1	5.9	6.5		6.6	6.7	7.4	+
CESO-20-20Avg	5.5	5.5	6.1	+	6.0	5.9	5.6	
CESO-16-16Avg	5.6	6.6	7.5	+	4.8	5.7	5.4	

5. INDENT DEPTH

5.1 General

The technical guidelines specify the recording of indent depth before and after environmental exposure. Indent depth is specified as the indentor spacing plus the snap-back of the contact barrel and wire, i.e., the radial bottom-to-bottom dimension of the crimps. The spacing of the indentors of the production crimping tool was set using precision wire gages. The indent depth of the crimped specimens was measured with an inspector's bench gage which had a lever-operated dial indicator with 1.0 mil-radius points.

This gage was adjusted and calibrated in the Tool and Gage Department. Considerable difficulty was experienced with the maintenance of calibration and in the uniformity of measurements from different inspectors. This made it necessary to record for reference purposes indent depth measurements of samples from each group made by one mechanical inspector using pointed micrometers. The indent depth data is primarily based upon the reference measurements.

5.2 Data Adjustments

The indent depth data as entered in the data log was reviewed for completeness prior to submission for card punching. It was reviewed again after card punching and after the processing which provided values of minimum, maximum, mean, and standard deviation for each group of measurements. The latter review pointed out outlying data points as well as data points with transposed figures. These were corrected individually on the data cards. The processed mean, maximum, and minimum values were compared with the sample indent depth measurements, and a judgement was made as to the existance of any bias error. If in the opinion of the reviewer one did exist, the whole data field was adjusted. The adjusted data is presented in this report. No attempt was made to adjust for the observed variations in data variability.

5.3 Data Analysis

The measured indent depth of the prepared specimens groups is given in table 9. The data, a tabulation of averaged mean values of indent depth for either single or double indent configuration of the male and female contacts, indicate general similarity with some evidence of greater "snap back" for the CE contacts. This could result from the fact that the crimp barrel inner diameter is 0.003 inch less than the same dimension of the NAS and MS contacts. The contacts crimped at the smallest indentor spacings appear to "snap back" more than the contacts crimped at the largest spacing. This an expected performance.

Contact Size / Indentor Spacing / Wire Size	NAS 1662		MS 3192	
	Single Indent	Double Indent	Single Indent	Double Indent
20-( )034-22	39.8	38.9	40.9	39.2
( )037	42.0	41.7	42.5	42.0
( )040	45.7	44.5	45.5	44.5
( )043	47.4	47.2	48.8	48.3
20-( )037-20	41.4	41.2	42.9	42.3
( )040	44.8	43.7	46.1	44.6
( )043	47.0	47.9	48.6	48.0
( )046	50.5	49.7	52.0	50.5
16-( )037-20	42.4	42.5	44.8	42.6
( )040	45.9	44.4	46.7	46.5
( )043	49.0	48.5	49.9	48.9
( )046	51.0	50.6	51.9	52.0
16-( )043-16	48.6	48.0	50.7	49.7
( )046	52.0	51.0	52.6	52.0
( )050	55.7	54.4	57.0	55.5
( )054	60.0	59.3	60.9	59.8

TABLE 9

AVERAGE MEASURED INDENT DEPTH OF
PREPARED SPECIMEN GROUPS
10^{-3} INCHES

BENDIX CEPI		NAS 1663		MS 3193		BENDIX CESO	
Single Indent	Double Indent	Single Indent	Double Indent	Single Indent	Double Indent	Single Indent	Double Indent
42.3 44.3 47.7 50.3	40.8 43.8 45.9 49.6	40.5 42.0 45.4 47.9	38.4 41.2 44.2 45.7	40.6 42.4 46.2 48.8	40.0 42.3 44.2 47.7	42.1 44.0 47.3 49.0	40.6 43.3 46.1 49.2
44.6 48.1 50.3 53.6	44.1 46.4 49.0 52.5	40.9 44.9 47.7 50.8	41.5 43.6 47.7 49.8	42.7 45.7 48.8 52.4	42.5 44.3 47.3 50.7	43.8 46.7 50.0 52.8	43.4 46.5 49.6 51.5
45.2 48.2 50.9 53.8	45.5 48.5 50.8 52.6	43.5 45.0 49.1 52.0	42.2 45.7 48.0 50.8	44.6 47.3 49.7 52.8	44.1 45.7 47.9 51.9	45.3 46.1 48.9 52.2	43.7 46.5 49.3 52.2
50.9 54.2 57.8 60.6	51.2 53.2 57.1 61.3	47.9 52.8 56.7 59.9	48.9 51.1 55.7 58.8	50.4 52.9 57.2 60.1	48.7 51.2 56.0 59.8	50.8 53.3 57.7 61.3	50.2 53.0 57.2 61.0

Additional reviewing of the processed data indicates that the indent depth increased slightly as a result of the temperature shock and temperature life tests. This cannot be stated with any certainty, since the data was not measured with the accuracy to prove that what was observed was not a purely random occurrence.

6. DEFORMATION AND AXIAL BENDING

6.1 General

The measurement of the extent of deformation of the crimped contact assemblies consisted of (1) Deformation Diameter (DDM), which is the maximum diameter of the barrel over the crimps, and (2) Axial Bending (ABM), which is the total eccentricity of the flared end of the contact barrel. For a majority of the sample specimens, these measurements were made with the same setup and same instrument, an optical comparator. After the data had been processed, it was necessary to reinspect several groups due to apparent operator error. This was particularly true for the DDM values. Two new groups of 24 specimens were prepared in order to overcome omissions in the transcribing of data. These latter measurements were made by a mechanical inspector using micrometer techniques for DDM and the optical comparator for the ABM measurements. The data summaries of measured DDM and ABM for the study groups are given in table 10.

6.2 Deformation

The values of the maximum diameter for the size-20 contacts range from 0.074 to 0.080 inch corresponding to decreasing indentor spacing. There is an indication that the double indent configuration produces greater deformation than does the single indent configuration.

The value of the maximum diameter for the size-16 contact ranges from 0.098 to 0.110 inch corresponding to decreasing indentor spacing. As with the size-20 contact, there is an indication that the double indent configuration produces greater deformation. This cannot be accepted due to possible error in reading the maximum diameter optically. The exception of note are the CESO-16-20 sample specimens which were measured by micrometer techniques.

6.3 Axial Bending

The values of axial bending (eccentricity) range from a few thousandths to mean values as high as 15 thousandths. The data pattern indicates that greater axial bending can be expected for the double indent configuration when compared to the corresponding single indent configuration. The magnitude of the bending in general appears to vary inversely as a function of the indentor spacing.

The exceptions noted in the data can possibly be a function of initial run-out of the contacts prior to crimping. Investigation discovered that less than 25 percent would pass the limits of 0.001-inch total run-out. The value was observed to exceed 0.005 inch for approximately 15 percent of the contacts.

TABLE 10

DATA SUMMARIES OF MEASURED
DEFORMATION (DDM) AND AXIAL
BENDING (ABM) FOR THE NAS 1662 CRIMPED CONTACTS
10^{-3} INCHES

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
1662-20( )034-22	78.6	2.6	79.2	7.5
( )037	78.6	3.4	78.6	4.8
( )040	78.6	5.9	76.2	3.8
( )043	77.8	3.1	76.7	3.1
1662-20( )037-20	80.1	2.8	79.6	6.3
( )040	79.1	3.4	78.8	5.4
( )043	77.4	2.6	78.3	4.1
( )046	77.9	2.9	78.0	5.7
1662-16( )037-20	102.4	7.7	104.2	12.3
( )040	102.4	7.2	102.2	9.0
( )043	102.4	7.2	101.7	9.4
( )046	102.5	6.7	100.0	9.9
1662-16( )043-16	105.5	7.3	106.7	10.4
( )046	104.6	7.2	105.7	9.9
( )050	103.9	7.2	104.0	11.5
( )054	102.4	6.0	102.1	6.6

TABLE 10 (Continued)

DATA SUMMARIES OF MEASURED
DEFORMATION (DDM) AND AXIAL
BENDING (ABM) FOR THE NAS 1663 CRIMPED CONTACTS
10^{-3} INCHES

Contact Type Contact Size ( ) Indentor Spacing Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
1663-20( )034-22	79.0	3.2	79.4	6.4
( )037	78.8	2.9	76.9	5.0
( )040	78.7	3.4	78.2	4.3
( )043	78.2	3.0	76.0	5.0
1663-20( )037-20	81.7	3.1	79.5	5.9
( )040	77.7	2.7	78.6	4.4
( )043	77.1	3.1	78.5	3.7
( )046	76.9	2.9	78.2	3.3
1663-16( )037-20	102.3	6.2	104.9	9.4
( )040	102.0	6.8	103.2	10.0
( )043	102.5	5.5	101.7	8.7
( )046	102.1	4.4	100.1	8.4
1663-16( )043-16	106.0	7.1	106.8	10.0
( )046	105.2	5.1	104.9	8.0
( )050	104.7	6.0	104.1	7.4
( )054	104.0	4.0	102.1	5.2

TABLE 10 (Continued)

DATA SUMMARIES OF MEASURED DEFORMATION (DDM) AND AXIAL BENDING (ABM) FOR THE MS 3192 CRIMPED CONTACTS 10^{-3} INCHES

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
3192-20( )034-22	76.9	3.4	79.7	15.4
( )037	75.8	4.6	77.4	9.3
( )040	75.9	3.9	76.7	8.2
( )043	74.7	3.0	75.5	5.9
3192-20( )037-20	77.5	4.2	79.6	9.8
( )040	77.8	3.0	77.6	9.0
( )043	77.1	3.6	76.8	7.0
( )046	76.9	4.0	76.2	3.2
3192-16( )037-20	104.2	2.8	105.2	7.5
( )040	104.0	2.9	105.0	6.6
( )043	104.1	2.7	104.2	5.4
( )046	104.2	2.5	101.9	5.2
3192-16( )043-16	110.2	2.5	109.4	11.5
( )046	110.0	2.4	107.3	8.0
( )050	107.6	2.8	105.2	5.3
( )054	105.6	2.7	104.0	7.4

TABLE 10 (Continued)

DATA SUMMARIES OF MEASURED
DEFORMATION (DDM) AND AXIAL
BENDING (ABM) FOR THE MS 3193 CRIMPED CONTACTS
10^{-3} INCHES

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
3193-20( )034-22	78.1	6.3	80.1	14.8
( )037	77.7	5.0	78.1	9.3
( )040	75.2	5.0	76.9	9.6
( )043	75.0	4.6	76.7	7.8
3193-20( )037-20	79.9	4.0	79.6	9.8
( )040	77.5	4.3	79.0	9.3
( )043	76.8	4.3	77.6	7.9
( )046	76.9	3.8	76.7	5.9
3193-16( )037-20	104.2	3.6	106.9	10.9
( )040	104.0	3.6	105.5	8.6
( )043	104.0	3.9	104.7	8.1
( )046	103.9	2.7	104.2	6.0
3193-16( )043-16	109.8	2.9	109.8	12.7
( )046	107.5	3.1	107.7	10.6
( )050	106.2	2.6	105.3	7.2
( )054	105.2	1.9	102.2	7.3

TABLE 10 (Continued)

DATA SUMMARIES OF MEASURED
DEFORMATION (DDM) AND AXIAL BENDING (ABM) FOR THE
BENDIX TYPE CE (PIN) CRIMPED CONTACTS
10^{-3} INCHES

Contact Type / Contact Size ( ) Indentor Spacing / Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
CEPI-20( )034-22	75.1	7.7	78.2	12.3
( )037	75.0	7.2	76.9	11.8
( )040	74.5	6.2	76.4	10.1
( )043	74.9	6.2	75.8	7.4
CEPI-20( )037-20	75.2	7.7	77.1	10.1
( )040	75.1	6.5	76.8	9.7
( )043	75.3	6.7	76.5	9.3
( )046	75.2	4.1	76.1	7.9
CEPI-16( )037-20	100.7	6.9	109.7	8.2
( )040	99.8	7.8	104.5	9.8
( )043	98.9	7.6	103.1	9.7
( )046	98.9	5.4	102.4	7.3
CEPI-16( )043-16	103.2	5.7	106.5	8.2
( )046	101.0	10.6	105.7	9.4
( )050	102.2	6.3	105.3	5.4
( )054	101.6	4.6	104.6	7.7

TABLE 10 (Continued)

DATA SUMMARIES OF MEASURED
DEFORMATION (DDM) AND AXIAL BENDING (ABM) FOR THE
BENDIX TYPE CE (SOCKET) CRIMPED CONTACTS
10^{-3} INCHES

Contact Type Contact Size Indentor Spacing Wire Size	Single Indent DDM	Single Indent ABM	Double Indent DDM	Double Indent ABM
CESO-20( )034-22	75.3	5.2	78.4	12.4
( )037	74.5	6.4	77.0	10.6
( )040	74.0	5.7	76.0	8.1
( )043	73.6	5.1	75.9	8.4
CESO-20( )037-20	76.1	6.0	76.6	11.6
( )040	74.5	6.2	76.6	11.0
( )043	73.7	5.2	75.7	7.0
( )046	74.0	4.3	76.3	7.0
CESO-16( )037-20	109.5	7.4	109.3	9.1
( )040	109.1	6.6	108.3	7.6
( )043	108.8	6.6	108.5	9.1
( )046	108.5	7.1	108.3	8.6
CESO-16( )043-16	101.9	6.3	105.8	9.2
( )046	101.5	6.3	104.2	8.3
( )050	101.4	5.9	103.3	8.4
( )054	101.4	4.2	102.7	5.2

7. CONCLUSION

It is concluded, based upon the results obtained from this "Study for the determination of the Indent Depth and Configuration for the Maximum Reliability Connections when Nickel Plated Copper Wire is crimped into Gold Plated Connector Contacts," that a double indent configuration at an indentor spacing that yields approximately equal incidents of wire fracture and wire slippage tensile test failures produces crimped contacts with maximum tensile strength and minimum variability. The tensile strength obtained approaches very closely the tensile strength of the wire. This conclusion is applicable for the 16 NAS and MS contact wire size combinations reported herein. This conclusion is indicated as being applicable to the CE-type contacts. The reservation being that the study did not include indentor spacings for the CE double indent which bracket the optimum or maximum tensile strength setting. The study did indicate that the CE double indent optimum indentor spacing would be greater by a value of three to six thousandths than the optimum for the single indent configuration.

It is concluded that the salt fog environment increases the tensile strength of the single indent configuration crimped contact assemblies. This was observed for 74 percent of the specimen groups. It is concluded that the salt fog environment decreased the tensile strength of the double indent configuration crimped contact assemblies. This was observed for 70 percent of the specimen groups. The results provide an indication of correlation that those groups which fail by the mechanism of wire slippage increase in tensile strength due to the presence of corrosion products at the crimp interface. This is indicated for both single and double indent configurations. The converse is also indicated, i.e., that reduction in tensile strength was observed after salt fog exposure for those groups having wire fracture as the failure mechanism.

It is concluded that there was not any significant difference in voltage drop for any of the specimen groups initially. It is concluded that with exposure to the environmental stresses that the conductance of the single indent groups decreases significantly more than the corresponding double indent groups. This conclusion is largely influenced by the performance of the NAS and MS groups. The results from the CE groups are not as pronounced.

The data gives indication of an indent depth increase as a function of the temperature stress test. The experiment was not structured to measure indent depth to the accuracy required to provide conclusive evidence, therefore no conclusion is made.

Deformation and axial bending of the contact barrel is greatest for those assemblies which are crimped to the smaller indentor spacings.

APPENDIX A

LIST OF PURCHASED MATERIALS

used in

A Study for the Determination
of the Indent Depth and Configuration
for the Maximum Reliability
Connections when Nickel Plated
Copper Wire is Crimped into
Gold Plated Connector Contacts

Contract No. NAS8-20407
(Melpar Job No. 6344.00100)

Prepared for

George C. Marshall Space Flight Center
Huntsville, Alabama

Submitted by

Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia 22046

May 1967

APPENDIX A

LIST OF PURCHASED MATERIALS FOR INDENT DEPTH AND CONFIGURATION STUDY

Item	Purchase Order Number	Supplier	Item Number	Quantity	Unit of Issue	Description	Call Order
1	C4028AA	Thermatics, Inc. Elm City, N.C.	01	1000	ft	Wire, No. 16 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
			02	1000	ft	Wire, No. 16 AWG, 19 strands, nickel-plated, Teflon E, green, per MIL-W-16878	
2	C4028AB	CIMCO Wire & Cable Co. Allendale, N.J.	01	1000	ft	Wire, No. 20 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
			02	1000	ft	Wire, No. 22 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
3	C4028AC	Brand Rex, Willimantic, Conn.	01	1000	ft	Wire, No. 22 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	

APPENDIX A (Continued)

Item	Purchase Order Number	Supplier	Item Number	Quantity	Unit of Issue	Description	Call Order
4	C4028AD	Haveg-Super Temp. Wire Division, Winooski, Vermont	01	2000	ft	Wire, No. 22 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
5	C4028AE	MIL-SPEC Supply, Inc., Van Nuys, Calif.	01	800	ft	Wire, No. 16 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
			02	4500	ft	Wire, No. 20 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
6	C4028AF	Sonic Wire Sales, Van Nuys, Calif.	01	1600	ft	Wire, No. 20 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
7	C4028AG	Standard Wire & Cable Co. Los Angeles, Calif.	01	471	ft	Wire, No. 16 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	
			02	300	ft	Wire, No. 20 AWG, 19 strands, nickel-plated, Teflon E, white, per MIL-W-16878	

APPENDIX A (Continued)

Item	Purchase Order Number	Supplier	Item Number	Quantity	Unit of Issue	Description	Call Order
8	C4028AH	MIL-SPEC Supply, Inc., Van Nuys, Calif.	01	500	ft	Wire, No. 22 AWG, 19 strands, nickel-plated, Teflon E, insulation color white, per MIL-W-16878	
9	C4028AI	Thermatics, Inc., Elm City, N.C.	01	1000	ft	Wire, No. 16 AWG, 19 strands, nickel-plated, Teflon E, green, per MIL-W-16878	
10	C4029A	Amp, Inc., Harrisburg, Pa.	01	2400	ea	Contact (MS319216A)	
			02	2400	ea	Contact (MS3192A20A)	
			03	2400	ea	Contact (MS319316A)	
			04	2400	ea	Contact (MS3193A20A)	
11	C4030A	Deutsch Electronic Components, Banning, Calif.	01	2400	ea	Contact (NAS-1662-16)	
			02	2400	ea	Contact (NAS-1662-20)	
			03	2400	ea	Contact (NAS-1663-16)	
			04	2400	ea	Contact (NAS-1663-20)	

APPENDIX A (Continued)

Item	Purchase Order Number	Supplier	Item Number	Quantity	Unit of Issue	Description	Call Order
12	C4031A	The Bendix Corp. (Scintilla) Sidney, N.Y.	01	2400	ea	Contact, 16 Pin (10-189004-162)	
			02	2400	ea	Contact, 20 Pin (10-189000-202)	
			03	1200	ea	Contact, Socket, No. 16 (10-189006-162)	
			04	2400	ea	Contact, Socket, No. 20 (10-189002-202)	
13	D1058A	Buchanan Electrical Products Union, N.J.	01	1	ea	Basic frame assembly, pneumatic crimping tool (MFT) (11221)	
			02	1	ea	Bench, 11380 Mount	
			03	1	ea	Locator, 3212 (20)	
			04	1	ea	Locator, 3213 (16)	
			05	1	ea	Locator, 11077 (CE-16)	
14	A0037C	Industrial Photo Silver Spring, Md.	01	1	case	Type 52 Polaroid Film, Land Film Packs 1 case containing 12 boxes of 12 exposures	393

APPENDIX A (Continued)

Item	Purchase Order Number	Supplier	Item Number	Quantity	Unit of Issue	Description	Call Order
15	A0081C	Earl B. Beach Co. Timonium, Md.	01	225	ft	Sleeving, RNF100, 1/16 in. ID, heat shrinkable, color - red	108
			02	400	ft	Sleeving, RNF100, 3/32 in. ID, heat shrinkable, color - blue	108
			03	225	ft	Sleeving, RNF100, 1/8 in. ID, heat shrinkable, color - yellow	108

APPENDIX B

SAMPLE GROUP IDENTIFICATION CODE

used in

A Study for the Determination of the Indent
Depth and Configuration for the
Maximum Reliability Connections
when Nickel Plated Copper Wire
is Crimped into Gold Plated
Connector Contacts

Contract No. NAS8-20407
(Melpar Job No. 6344.00100)

Prepared for

George C. Marshall Space Flight Center
Huntsville, Alabama

Submitted by

Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia 22046

May 1967

APPENDIX B

SAMPLE IDENTIFICATION CODE

Explanation of Sample Code

	Contact Type	Contact Size	Indent	Indentor Spacing	Wire Size
Abbrev.	C T	C S	I	I S	W S
IBM Col.	1 2 3 4	6 7	9	10 11 12	14 15
	1 6 6 2	2 0	S	0 3 4	2 2
	1 6 6 3	1 6	D	0 3 7	2 0
	3 1 9 2			0 4 0	1 6
	3 1 9 3			0 4 3	
	C E P I			0 4 6	
	C E S O			0 5 0	
				0 5 4	
				0 3 2	
				0 5 9	

INDENT CODE USED FOR SAMPLE GROUP

Lot	Identity	Serial Number
1662	20 S034 22	001
1662	20 S037 22	002
1662	20 S040 22	003
1662	20 S043 22	004
1662	20 D034 22	005
1662	20 D037 22	006
1662	20 D040 22	007
1662	20 D043 22	008
1662	20 S037 20	009
1662	20 S040 20	010
1662	20 S043 20	011
1662	20 S046 20	012
1662	20 D037 20	013
1662	20 D040 20	014
1662	20 D043 20	015
1662	20 D046 20	016
1662	16 S037 20	017
1662	16 S040 20	018
1662	16 S043 20	019
1662	16 S046 20	020
1662	16 D037 20	021
1662	16 D040 20	022
1662	16 D043 20	023
1662	16 D046 20	024
1662	16 S043 16	025
1662	16 S046 16	026
1662	16 S050 16	027
1662	16 S054 16	028
1662	16 D043 16	029
1662	16 D046 16	030
1662	16 D050 16	031
1662	16 D054 16	032
1663	20 S034 22	033
1663	20 S037 22	034
1663	20 S040 22	035
1663	20 S043 22	036
1663	20 D034 22	037
1663	20 D037 22	038
1663	20 D040 22	039
1663	20 D043 22	040
1663	20 S037 20	041
1663	20 S040 20	042
1663	20 S043 20	043
1663	20 S046 20	044
1663	20 D037 20	045
1663	20 D040 20	046
1663	20 D043 20	047
1663	20 D046 20	048
1663	16 S037 20	049
1663	16 S040 20	050
1663	16 S043 20	051
1663	16 S046 20	052
1663	16 D037 20	053
1663	16 D040 20	054
1663	16 D043 20	055
1663	16 D046 20	056
1663	16 S043 16	057
1663	16 S046 16	058
1663	16 S050 16	059
1663	16 S054 16	060

INDENT CODE USED FOR SAMPLE GROUP (Cont.)

Lot	Identity	Serial Number
1663	16 D043 16	061
1663	16 D046 16	062
1663	16 D050 16	063
1663	16 D054 16	064
3192	20 S034 22	065
3192	20 S037 22	066
3192	20 S040 22	067
3192	20 S043 22	068
3192	20 D034 22	069
3192	20 D037 22	070
3192	20 D040 22	071
3192	20 D043 22	072
3192	20 S037 20	073
3192	20 S040 20	074
3192	20 S043 20	075
3192	20 S046 20	076
3192	20 D037 20	077
3192	20 D040 20	078
3192	20 D043 20	079
3192	20 D046 20	080
3192	16 S037 20	081
3192	16 S040 20	082
3192	16 S043 20	083
3192	16 S046 20	084
3192	16 D037 20	085
3192	16 D040 20	086
3192	16 D043 20	087
3192	16 D046 20	088
3192	16 S043 16	089
3192	16 S046 16	090

Lot	Identity	Serial Number
3192	16 S050 16	091
3192	16 S054 16	092
3192	16 D043 16	093
3192	16 D046 16	094
3192	16 D050 16	095
3192	16 D054 16	096
3193	20 S034 22	097
3193	20 S037 22	098
3193	20 S040 22	099
3193	20 S043 22	100
3193	20 D034 22	101
3193	20 D037 22	102
3193	20 D040 22	103
3193	20 D043 22	104
3193	20 S037 20	105
3193	20 S040 20	106
3193	20 S043 20	107
3193	20 S046 20	108
3193	20 D037 20	109
3193	20 D040 20	110
3193	20 D043 20	111
3193	20 D046 20	112
3193	16 S037 20	113
3193	16 S040 20	114
3193	16 S043 20	115
3193	16 S046 20	116
3193	16 D037 20	117
3193	16 D040 20	118
3193	16 D043 20	119
3193	16 D046 20	120

INDENT CODE USED FOR SAMPLE GROUP (Cont.)

Lot	Identity	Serial Number	Lot	Identity	Serial Number
3193	16 S043 16	121	CEPI	16 S043 16	153
3193	16 S046 16	122	CEPI	16 S046 16	154
3193	16 S050 16	123	CEPI	16 S050 16	155
3193	16 S054 16	124	CEPI	16 S054 16	156
3193	16 D043 16	125	CEPI	16 D043 16	157
3193	16 D046 16	126	CEPI	16 D046 16	158
3193	16 D050 16	127	CEPI	16 D050 16	159
3193	16 D054 16	128	CEPI	16 D054 16	160
CEPI	20 S034 22	129	CESO	20 S034 22	161
CEPI	20 S037 22	130	CESO	20 S037 22	162
CEPI	20 S040 22	131	CESO	20 S040 22	163
CEPI	20 S043 22	132	CESO	20 S043 22	164
CEPI	20 D034 22	133	CESO	20 D034 22	165
CEPI	20 D037 22	134	CESO	20 D037 22	166
CEPI	20 D040 22	135	CESO	20 D040 22	167
CEPI	20 D043 22	136	CESO	20 D043 22	168
CEPI	20 S037 20	137	CESO	20 S037 20	169
CEPI	20 S040 20	138	CESO	20 S040 20	170
CEPI	20 S043 20	139	CESO	20 S043 20	171
CEPI	20 S046 20	140	CESO	20 S046 20	172
CEPI	20 D037 20	141	CESO	20 D037 20	173
CEPI	20 D040 20	142	CESO	20 D040 20	174
CEPI	20 D043 20	143	CESO	20 D043 20	175
CEPI	20 D046 20	144	CESO	20 D046 20	176
CEPI	16 S037 20	145	CESO	16 S043 16	177
CEPI	16 S040 20	146	CESO	16 S046 16	178
CEPI	16 S043 20	147	CESO	16 S050 16	179
CEPI	16 S046 20	148	CESO	16 S054 16	180
CEPI	16 D037 20	149	CESO	16 D043 16	181
CEPI	16 D040 20	150	CESO	16 D046 16	182
CEPI	16 D043 20	151	CESO	16 D050 16	183
CEPI	16 D046 20	152	CESO	16 D054 16	184

IDENT CODE USED FOR SAMPLE GROUP (Cont.)

Lot	Identity	Serial Number
1662	20 D032 22	201
1662	20 D034 20	202
1662	16 D040 16	203
1663	20 D032 22	204
1663	20 D034 20	205
3192	16 D050 20	206
3193	20 D032 22	207
3193	16 D050 20	208
CE PI	20 D046 22	209
CE PI	20 D050 20	210
CE PI	16 D050 20	211
CE PI	16 D059 16	212
CE PI	16 D050 20	213
CE PI	16 D059 16	214
CESO	16 S037 20	301
CESO	16 S040 20	302
CESO	16 S043 20	303
CESO	16 S046 20	304
CESO	16 D037 20	305
CESO	16 D040 20	306
CESO	16 D043 20	307
CESO	16 D046 20	308

APPENDIX C

ENVIRONMENTAL EXPOSURES
SAMPLE OF SPECIMENS

used in

A Study for the Determination of the
Indent Depth and Configuration for the
Maximum Reliability Connections
when Nickel Plated Copper Wire is
Crimped into Gold Plated Connector Contacts

Contract No. NAS8-20407
(Melpar Job No. 6344.00100)

Prepared for

George C. Marshall Space Flight Center
Huntsville, Alabama

Submitted by

Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia 22046

May 1967

TEST and EVALUATION REQUEST
QC-287, 1/65 NCR PAPER

NO. 1602

Job No.	Sec. Class. (Test Specimen)	Cognizant Eng.	Location	Ext.	
6344. 00100		B. H. Dennison	FC	2553	Date of Request Nov. 25, 1966 Date Specimen Del. to Lab. Nov. 28, 1966 Requested Date of Completion Dec. 24, 1966

Personnel Assigned to Test	Type of Report Requested	Witness Required
	Return parts with certification that they were exposed.	MELPAR QC Air Force Other (Specify)

TEST

Test Requested	Name of Specimen	Part No. of Specimen / Serial No. of Specimen
Per quotation	Crimp Indent Depth - 184 sample lots of 50 crimps (25 wires)	

Purpose of Test (Summarize)

Part of study of reliability of single and double indent crimped contacts -- gold-plated or nickel-plated wire.

Sketch or Description of Desired Test Setup

Environmental Test per MIL-STD-202B

1. Thermal Shock per Method 107A, Test Condition "C"
2. Temperature Cycling per Method 102A, Test Condition "D"
3. Life Test per Method 108, Test Condition "B"
4. Vibration Test per Method 204B, Test Condition "B"

References (Documents which detail environmental conditions under which test is to be conducted)

NAS8-20407
Exhibit "A" Scope of Work

B. H. Dennison — Originator — Ext. 2553
B. H. Dennison — Approved — Ext. 2553

TO BE COMPLETED BY TEST AND EVALUATION LABORATORY

		Date
Test Engineer	Request Rec'd	12/1/66
Equipment	Specimen Rec'd	12/1/66
	Plan Completed	12/1/66
	Test Scheduled	12/1/66
	Test Completed	1/12/67
	Report Issued	

Estimated Hrs. 125 Actual Hrs. 96.75 Hrs.

Approved E. Parrish Date 1/23/67

ENVIRONMENTAL TEST LABORATORY
TEST REPORT
DC-130, 9/60

Page ______ of ______

TEST ITEM	
NAME: 184 Sample Lots of Cables with Crimp Indent Terminals on each end.	DATE: 20 January 1967
	JOB NO.: 6344.00100
PART NO.: Not applicable	TEST REQUEST NO.: 1602
SERIAL NO.: Not applicable	ORIGINATOR: B. H. Dennison
MANUFACTURER: Melpar, Inc.	TEST DATE: 8 Dec. 1966 to 12 Jan. 1967
TYPE OF TEST: Thermal Shock, Temperature Cycling, Life Test & Vibration	TEST ENGINEER: A. R. Chouinard

OPERATORS	OBSERVERS	TEST EQUIPMENT
J. C. Coleman C. S. Barrett R. W. Baker	None	(1) Ling Vibration Exciter, TI 2997-1 (2) Ling Power Amplifier TI 1800-1 (3) Glennite Cathode Follower, TI 525-3 (4) Endevco Accelerometer, TI 1288-1 (5) MB Vibration Control Console, TI 3244-1 (6) Tenney Stratosphere Chamber, TI 968-1 (7) Honeywell Temperature Recorder Controller, TI 2073-1 (8) Honeywell Temperature Recorder, TI 907-1 (9) L and N Potentiometer, TI 1304-2 (10) Partlow Oven, TI 1939-1 (11) Thermocouple Reference Junction Box, T.J. 547-2 (12) Bowser Stratosphere Chamber, TI 967-1

1.0 Purpose

1.1 To subject 184 sample lots of 25 wires each to environmental tests as specified in MIL-STD-202B as listed below:

1. Thermal Shock, Method 107A, Test Condition C.

2. Temperature Cycling, Method 102A, Test Condition D.

3. Life Test, Method 108, Test Condition B.

4. Vibration Test, Method 204B, Test Condition B.

2.0 Results

2.1 Thermal Shock testing of 184 sample lots of 25 wires each was completed as specified in MIL-STD-202B, Method 107A, Test Condition C. The visual examinations, after conclusion of Thermal Shock testing, did not disclose any apparent external effects.

2.2 Temperature cycling of 184 sample lots of 25 wires each was completed as specified in MIL-STD-202B, Method 102A, Test Condition D. The visual examination after conclusion of Temperature Cycling did not disclose any apparent effects.

2.3 Life testing of 184 sample lots of 25 wires each was completed as specified in MIL-STD-202B, Method 108, Test Condition B. The visual examination after completion of the test did not disclose any apparent effects.

2.4 Vibration testing of 184 sample lots of 25 wires each was completed as specified in MIL-STD-202B, Method 204B, Test Condition B. The visual examination after completion of two directions (8 hours of vibration) disclosed that the wire to one terminal was broken where the wire entered the crimp portion of the terminal.

The terminal ends of each wire were not supported in any manner and were free to resonate as cantilever beams. During the vibration cycling, each spring mass system (each terminal at the ends of the cables) resonated at a natural resonant frequency dictated by each system. Since the terminals were loose and free to move, most of the flexing was at the point where the wires entered the terminals. These points on the cables were considered as having the worst response and accounts for the one broken wire. No other effects were observed.

3.0 Procedure

3.1 Thermal Shock

3.1.1 All the sample lots of wires were tied to a metal rack with nylon lacing cord.

3.1.2 Two chambers were utilized for this test. The Tenney Stratosphere Chamber was operated at -85°F to -91°F for the low-temperature portion of the test. An oven was preconditioned at a temperature of approximately +80°F in excess of +401°F to compensate for the decrease in temperature which resulted when the cables were placed into the chamber and to insure that the test items were subjected to the required temperatures within 2 minutes after the chamber door was closed. Beaded copper-constantan thermocouples were installed in each chamber to monitor the temperature near the location of the test samples.

3.1.3 The rack supporting the cables was transferred among the three environments according to the following schedule:

Temperature, °F	Time in minutes
-85°F - 9, + 0	30
+ 77°F ± 2	5
+ 392°F + 9, - 0	30
+ 77°F ± 2	5

The above constituted one complete cycle. Thermocouple readings were recorded 2 minutes after installation of the samples to assure that the chambers met the thermal capacity requirements of Method 107A of MIL-STD-202B. A total of five continuous complete cycles was performed.

3.1.4 The samples were visually examined after completion of the fifth cycle.

3.2 Temperature Cycling

3.2.1 The same general procedure was used as for Thermal Shock testing except that the samples were cycled according to the schedule listed below:

Temperature, °F	Time in minutes
-67°F - 3, + 0	30
+77°F ± 2	15
+185°F + 5, 0	30
+77°F ± 2	15

After the end of the fifth cycle, the samples were visually examined.

3.3 Life Testing

3.3.1 The rack supporting the samples was installed in the Bowser Stratosphere Chamber.

3.3.2 The chamber temperature was increased to +185°F and held at this temperature for 263 hours. At the end of this period, the samples were removed from the chamber and examined.

3.4 Vibration

3.4.1 The samples were attached to a circular aluminum plate with steel shipping bands. The portions of the cables in contact with the slippery bands were padded with rubber isomode pads.

3.4.2 The samples were vibrated for 4 hours along each of the three mutually perpendicular directions at an input of 0.060 inches double amplitude between 10 Hz and 70 Hz and with an input of 15 G between 70 Hz and 2000 Hz. A logarithmic frequency sweep with the time adjusted to traverse the frequency range from 10 to 2000 and return 10 Hz in 20 minutes was used throughout the total of 12 hours of vibration.

3.4.3 The input displacement level was monitored from the output of the excitation velocity generator system. The input acceleration level was monitored from the output of a piezoelectric accelerometer on the aluminum plate near the samples.

3.4.4 Polaroid photographs were taken of each vibration test setup and are included with this report.

4.0 Disposition

4.1 The cable samples were returned to Mr. B. H. Dennison of the Research Division at Falls Church.

Approved: E Parrish
E. Parrish, Supervisor
Test and Evaluation Branch

A. R. Chouinard
A. R. Chouinard, Sr. Engineer
Test and Evaluation Branch

ENVIRONMENTAL TEST DATA SHEET

PAGE 1 OF

TEST ITEM

NAME Cables

PART NO.

SERIAL NO.

MANUFACTURER

TEST EQUIPMENT

Tenney Chamber TI 968-1

Honeywell Recorder TI 2073-1

Honeywell Recorder TI 907-1

L&N Bridge TI 1304-2

Hi-Temp. Oven TI 1939-1

NAME OF TEST

Thermal Shock

TEST SPECIFICATION

DATE Dec. 8, 1966

JOB NO. 6344.00100

TEST REQUEST NO. 1602

TEST ENGR. A. R. Chouinard

OPERATOR J. Coleman

WITNESSES

Time	Tenney Temp.		R.T.		Hi-Temp Oven		Notes
0818	-90°F		--		--		Cables Placed in Tenney chamber.
0820	-87°F		--		--		
0848	-90°F		+77°F		--		Cables removed.
0849	--		+77°F		+400°F		Cables placed in oven.
0851	--		--		+330°F		
0919	--		77°F		+394°F		Cables removed. (End cycle #1)
0920	-90°F		77°F		--		Cables placed in Tenney chamber.
0922	-79°F		--		--		
0950	-86°F		--		--		Removed from Tenney
0951	-86°F		77°F		--		
0955	--		--		+480°F		Placed in Hi-Temp oven.
0957	--		--		+384°F		
1001	--		--		+372°F		
1004	--		--		+392°F		
1025	--		--		+400°F		Cables removed. (End cycle #2)
1030	-90°F		77°F		--		Cables placed in Tenney chamber
1032	-91°F		--		--		
1100	-91°F		77°F		--		Cables removed.
	--		°F		°F		
1105	--		--		546°F		Cables in oven (Hi-Temp.)
1107	--		--		502°F		
1115	--		--		+401°F		
1135	--		78°F		+398°F		Cables removed (End cycle #3)
1140	-90°F		--		--		Cables placed in Tenney chamber.

DATA RECORDER JC CB

SUPPLEMENTARY

ENVIRONMENTAL TEST DATA SHEET

TEST ITEM

NAME Cables

PART NO.

SERIAL NO.

MANUFACTURER

NAME OF TEST

Thermal Shock

DATE 12-8-66

JOB NO. 6344.00100

TEST REQUEST NO. 1602

DATA SOURCE

Time	Tenney Temp.		R.T.		Hi-Temp Oven		Notes
1142	-89°F		--		--		
1210	--		77°F		--		Removed from Tenney chamber
1215	--		78°F		498°F		Placed in Hi-Temp oven
1217	--		--		406°F		
1245	--		77°F		396°F		Removed from Hi-Temp (End cycle #4)
1250	-90°F		78°F		--		Placed in Tenney
1252	-89°F		--		--		
1320	-89°F		78°F		--		Cables removed.
1325	--		78°F		550°F		Placed in Hi-Temp oven
1327	--		--		403°F		
1340	--		--		392°F		Back in Spec.
1355	--		79°F		395°F		Cables removed (End cycle #5)
1400	-91°F		79°F		--		Cables placed in Tenney
1402	-89°F		--		--		
1430	-90°F		79°F		--		Removed from Tenney
1435	--		79°F		525°F		Placed in Hi-Temp. oven
1437	--		--		401°F		
1441	--		--		350°F		
1446	--		--		392°F		Back in Spec.
1505	--		79°F		398°F		Removed from Hi-Temp. oven (End cycle #6)
1510	-90°F		79°F		--		Placed in Tenney Chamber
1512	-88°F		--		--		
1540	-88°F		79°F		--		Removed from Tenney
1545	--		79°F		525°F		Placed in oven
1547	--		--		404°F		
1551	--		--		368°F		

DATA RECORDER JC CB

PAGE 3 OF __

SUPPLEMENTARY

ENVIRONMENTAL TEST DATA SHEET

TEST ITEM

NAME Cables

PART NO.

SERIAL NO.

MANUFACTURER

NAME OF TEST

Thermal Shock

DATE 12-8-66

JOB NO. 6344.00100

TEST REQUEST NO. 1602

DATA SOURCE

Time	Tenney Temp.		R.T.		Hi-Temp Oven		Notes	
1555	--		--		392°F		Back in Spec.	
1615	--		79°F		397°F		Removed from oven	
1620	--		79°F		--		End cycle #7	
							End Test.	

DATA RECORDER CB JC

ENVIRONMENTAL TEST DATA SHEET

PAGE ___ OF ___

TEST ITEM

NAME Cables
PART NO.
SERIAL NO.
MANUFACTURER

DATE Dec. 9, 1966
JOB NO. 6344.00100
TEST REQUEST NO. 1602
TEST ENGR. A. R. Chouinard
OPERATOR J. Coleman
C. Barrett
WITNESSES

NAME OF TEST

Temp. Cycling

TEST EQUIPMENT

Tenney Chamber (TI 968-1)
Hi-Temp. Oven (TI 1939-1)
Temp. Recorder (TI 907-1)
L&N Potentiometer (TI 1304-2)
T.C. REF. Junction Box (TI 547-2)

TEST SPECIFICATION

Time	Tenney Chamber		R.T.		Hi-Temp Oven		Notes
	(TI 907-1)				(TI 1304-2)		
0821	-72°F		--		--		In cold (Tenney Chamber)
0823	-68°F		--		--		
0851	-68°F		77°F		--		Removed from cold
0906	--		--		188°F		Placed in Hi-Temp oven
0908	--		--		184°F		
0936	--		77°F		189°F		Removed from Hi-Temp. Oven (End cycle #1)
0951	-71°F		77°F		--		Placed in Tenney Chamber
0953	-70°F		--		--		
1021	-70°F		78°F		--		Removed from Tenney Chamber
1036	--		78°F		188°F		Placed in Hi-Temp. oven
1038	--		--		189°F		
1106	--		78°F		186°F		Removed from oven (End cycle #2)
1121	-71°F		78°F		--		Placed in Tenney Chamber
1123	-68°F		--		--		
1151	-69°F		78°F		--		Removed from Tenney Chamber
1206	--		--		188°F		Placed in Hi-Temp.
1208	--		--		186°F		
1236	--		78°F		190°F		Removed from Hi-Temp (End cycle #3)
1251	-68°F		78°F		--		Placed in Tenney Chamber
1253	-70°F		--		--		
1321	-68°F		79°F		--		Removed from Tenney Chamber
1336	--		79°F		186°F		Placed in oven.
1338	--		--		190°F		

DATA RECORDER J.C. C.B.

TEST ITEM

NAME Cables
PART NO.
SERIAL NO.
MANUFACTURER

SUPPLEMENTARY

ENVIRONMENTAL TEST DATA SHEET

NAME OF TEST

Temp. Cycling

DATE Dec. 9, 1966
JOB NO. 6344.00100
TEST REQUEST NO. 1602
DATA SOURCE

Time	Tenney Chamber		R.T.		Hi-Temp Oven		Notes
1406	--		79°F		189°F		Remove from Hi-Temp. (End cycle #4)
1421	-68°F		79°F		--		Placed in Tenney Chamber
1423	-68°F		--		--		
1451			79°F				Removed from Tenney Chamber
1506	--		--		189°F		Placed in Hi-Temp
1508	--		--		190°F		
1536	--		79°F		--		Removed from Hi-Temp (End cycle #5)

DATA RECORDER J.C. C.B.

TEST ITEM	ENVIRONMENTAL TEST DATA SHEET	PAGE 1 OF
NAME Cables		DATE Dec. 12, 1966
PART NO.		JOB NO. 6344.00100
SERIAL NO.	NAME OF TEST	TEST REQUEST NO. 1602
MANUFACTURER		TEST ENGR. A. R. Chouinard
	Life (Temp.)	OPERATOR C. Barrett
TEST EQUIPMENT Bowser Chamber TI 967-1	TEST SPECIFICATION	WITNESSES

Date	Time	Chamber Chart					Notes
12-12-66	0840	22°C					Cables placed in Bowser Chamber.
12-12-66	0920	85°C					Start 250 hour test
12-13-66	0800	85°C					Con't. Test 23
12-14-66	0800	85°C					Con't. Test 47
12-15-66	0800	85°C					Con't. Test 71
12-16-66	0808	85°C					Con't. Test 95
12-19-66	1235	85°C					Con't. Test 171
12-20-66	0850	85°C					Con't. Test 191
12-22-66	0850	85°C					Con't. Test 239
12-23-66	0800	85°C					End Test 263

Due to end on 22 Dec.

DATA RECORDER C & B

TEST ITEM

NAME Cables (Crimp Indent)

PART NO.

SERIAL NO.

MANUFACTURER Melpar, Inc.

ENVIRONMENTAL TEST DATA SHEET

PAGE ___ OF ___

DATE 9 January 1967

JOB NO. 6344.00100

TEST REQUEST NO. 1602

TEST ENGR. R. W. Baker

OPERATOR R. W. Baker

NAME OF TEST

Vibration

TEST EQUIPMENT

Ling A300B T.I.

Accl. #5277

Glennite Cathode Follower

Ling Power Supply T.I. 1800-1

TEST SPECIFICATION

MIL-STD-202B

Method 204A, Test Condition B

WITNESSES None

Date	Times		Freq	DA	G	Cycles	Sweep Settings 10 x 1.70 / 1.80
	Start	Stop	(Hz)	(inches)	(peak)	Com-pleted	
9 Jan 67	1458		10-70	0.060			First Cycle (vertical)
9 Jan 67			70-2kc -70		15.0		
9 Jan 67		1518	70-10	0.060		1	
9 Jan 67	1518	1538	10-2kc -10	0.060	15.0	2	
9 Jan 67	1538	1558	10-2kc -10	0.060	15.0	3	
9 Jan 67	1558	1618	10-2kc -10	0.060	15.0	4	
9 Jan 67	1618	1638	10-2kc -10	0.060	15.0	5	
9 Jan 67	1638	1658	10-2kc -10	0.060	15.0	6	
9 Jan 67	1658	1718	10-2kc -10	0.060	15.0	7	
10 Jan 67	0801	0821	10-2kc -10	0.060	15.0	8	
10 Jan 67	0821	0841	10-2kc -10	0.060	15.0	9	
10 Jan 67	0841	0901	10-2kc -10	0.060	15.0	10	
10 Jan 67	0901	0921	10-2kc -10	0.060	15.0	11	
10 Jan 67	0921	0941	10-2kc -10	0.060	15.0	12	

DATA RECORDER R. W. Baker

SUPPLEMENTARY

ENVIRONMENTAL TEST DATA SHEET

TEST ITEM

NAME Cables (Crimp Indent)

PART NO. ___

SERIAL NO. ___

MANUFACTURER Melpar, Inc.

NAME OF TEST

Vibration

DATE 10 January 1967

JOB NO. 6344.00100

TEST REQUEST NO. 1602

DATA SOURCE ___

MIL-STD-202B, Method 204A, Test Condition B

Date	Times		Freq	DA	G	Cycles				
	Start	Stop	(Hz)	(inches)	(peak)	Com-pleted				
10 Jan 67	1245	/	10-70	0.060	—					
10 Jan 67	/	/	70-2kc -70	—	15.0					
10 Jan 67	/	1305	70-10	0.060	—	1				
10 Jan 67	1305	1325	10-2kc -10	0.060	15.0	2				
10 Jan 67	1325	1345	10-2kc -10	0.060	15.0	3				
10 Jan 67	1345	1405	10-2kc -10	0.060	15.0	4				
10 Jan 67	1405	1425	10-2kc -10	0.060	15.0	5				
10 Jan 67	1425	1445	10-2kc -10	0.060	15.0	6				
10 Jan 67	1445	1505	10-2kc -10	0.060	15.0	7				
10 Jan 67	1505	1525	10-2kc -10	0.060	15.0	8				
10 Jan 67	1525	1545	10-2kc -10	0.060	15.0	9				
10 Jan 67	1545	1605	10-2kc -10	0.060	15.0	10				
10 Jan 67	1605	1625	10-2kc -10	0.060	15.0	11				
10 Jan 67	1625	1645	10-2kc -10	0.060	15.0	12				

One terminal broken off.

No other effects observed.

DATA RECORDER R. W. Baker

PAGE __ OF __

SUPPLEMENTARY

ENVIRONMENTAL TEST DATA SHEET

TEST ITEM
NAME Cables (Crimp Indent)
PART NO.
SERIAL NO.
MANUFACTURER Melpar, Inc.

NAME OF TEST
Vibration

DATE 11 January 1967
JOB NO. 6344.00100
TEST REQUEST NO. 1602
DATA SOURCE

MIL-STD-202B, Method 204A, Test Condition B

Date	Times		Freq	DA	G	Cycles				
	Start	Stop	(Hz)	(inches)	(peak)	Completed				
11 Jan 67	1245		10-70	0.060						
11 Jan 67			70-2kc -70		15.0					
11 Jan 67		1305	70-10	0.060		1				
11 Jan 67	1305	1325	10-2kc -10	0.060	15.0	2				
11 Jan 67	1325	1345	10-2kc -10	0.060	15.0	3				
11 Jan 67	1345	1405	10-2kc -10	0.060	15.0	4				
11 Jan 67	1405	1425	10-2kc -10	0.060	15.0	5				
11 Jan 67	1425	1445	10-2kc -10	0.060	15.0	6				
11 Jan 67	1445	1505	10-2kc -10	0.060	15.0	7				
11 Jan 67	1505	1525	10-2kc -10	0.060	15.0	8				
11 Jan 67	1525	1545	10-2kc -10	0.060	15.0	9				
11 Jan 67	1545	1605	10-2kc -10	0.060	15.0	10				
11 Jan 67	1605	1625	10-2kc -10	0.060	15.0	11				
11 Jan 67	1625	1645	10-2kc -10	0.060	15.0	12				
	No apparent damage.									

DATA RECORDER R. W. Baker

EST and EVALUATION REQUEST
QC-287, 1/65 NCR PAPER

NO. 1761

ob No.	Sec. Class. (Test Specimen)	Cognizant Eng.	Location	Ext.	
344. 0100		B. H. Dennison	FC	2553	Date of Request March 1, 1967 Date Specimen Del. to Lab. March 2, 1967 Requested Date of Completion March 12, 1967

rsonnel Assigned to Test	Type of Report Requested	Witness Required
	SALT FOG DATA	MELPAR QC Air Force Other (Specify)

TEST

st Requested	Name of Specimen	Part No. of Specimen / Serial No. of Specimen
Salt Fog, 1/2%, 50°C, 10 Days	184 Six wire groups	

rpose of Test (Summarize)

The purpose of the test is to determine the extent of corrosion and degradation for the sample crimped contacts prepared from nickel plated copper wire and gold plated contacts. The specimens will be tested for electrical and mechanical properties, i.e., voltage drop and tensile strength.

ketch or Description of Desired Test Setup

The tied bundles of wire specimens shall be suspended by the cord loops.

erences (Documents which detail environmental conditions under which test is to be conducted)

MIL-STD-202C, "Test Methods for Electronic and Electrical Component Parts" Method 101B "Salt Spray (Corrosion)" Modified for 1/2% Concentration, 50°C, and 10 Days / TEL Estimate of 1/10/67

B H Dennison — Originator — Ext. 2553

[signature] — Approved — Ext. 2147

TO BE COMPLETED BY TEST AND EVALUATION LABORATORY

st Engineer________

ipment________

	Date
Request Rec'd	3/1/67
Specimen Rec'd	
Plan Completed	
Test Scheduled	
Test Completed	
Report Issued	3/15/67

Parrish — Approved — Date 3/15/67

mated Hrs.______ Actual Hrs.______

QC-313, 2/65

MELPAR, INC.

TEST AND EVALUATION LABORATORY

SALT FOG TEST REPORT

DATE 15 March 1967

TEST REQUEST NUMBER 1761 JOB NUMBER 6344.00100

ORIGINATOR (Name & Group) B. H. Dennison

TEST SAMPLES (Number & Description) 184 Groups of Six Nickel Plated Wire Per Group Equipped with Gold Plated Crimp Connectors at each end.

APPLICABLE SPECIFICATIONS OR PROCEDURES

TEST SAMPLES MIL-STD-202C, Method 101B, Modified for 1/2% salt solution.

CHAMBER OPERATION 50°C Temperature, 1/2% salt solution.

ANGLE OF EXPOSURE Horizontal

DURATION OF EXPOSURE 10 days

DATES OF EXPOSURE From 3/3/67 to 3/13/67

RESULTS Immediately upon completion of the ten day test, the test items were removed from the chamber and rinsed with distilled water. An examination conducted at this time revealed only minor salt deposits on the majority of the connectors. No rust or corrosion was apparent on any of the samples.

A similar examination conducted on the test items approximately 24 hours after completion of the test revealed some slight corrosion in the crimp areas of the connectors on a small percentage of the samples.

Approved: E. Parrish

E. Parrish, Manager
Test and Evaluation Laboratory

A. R. Chouinard

A. R. Chouinard, Sr. Engineer
Test and Evaluation Laboratory

APPENDIX D

DATA SUMMARY VOLTAGE DROP
OF INDENT STUDY GROUPS

used in

A Study for the Determination of the Indent Depth and Configuration for the Maximum Reliability Connections when Nickel Plated Copper Wire is Crimped into Gold Plated Connector Contacts

Contract No. NAS8-20407
(Melpar Job No. 6344.00100)

Prepared for
George C. Marshall Space Flight Center
Huntsville, Alabama

Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia 22046

May 1967

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent VD_B	Single Indent VD_E	Single Indent VD_S	ΔVD	Double Indent VD_B	Double Indent VD_E	Double Indent VD_S	ΔVD
1662-20 ( ) 034-22	5.43	6.30	9.67	4.24	5.07	5.01	6.00	0.93
( ) 037	6.40	9.74	12.23	5.83	5.57	6.61	8.29	2.72
( ) 040	6.20	6.81	13.49	7.29	8.41	10.74	14.39	5,98
( ) 043	5.34	8.40	16.05	9.71	7.78	8.17	11.33	3.55
1662-20-22 Avg.	5.84	7.81	12.86		7.07	7.63	10.00	
1662-20 ( ) 037-20	6.38	7.83	16.12	9.74	5.05	4.54	5.64	0.59
( ) 040	5.81	9.91	19.18	13.37	5.07	5.24	9.82	4.75
( ) 043	7.60	10.56	22.51	14.91	5.93	5.80	9.66	3.73
( ) 046	6.04	7.37	13.97	7.93	5.57	6.12	10.96	5.39
1662-20-20 Avg.	6.45	8.92	18.04		5.41	5.43	9.02	
1662-16 ( ) 037-20	5.00	5.47	10.27	5.27	4.38	4.62	5.71	1.09
( ) 040	6.47	8.85	16.01	9.54	5.40	5.67	6.88	1.48
( ) 043	8.94	14.32	34.52	25.58	4.75	5.87	9.51	4.76
( ) 046	8.86	14.97	37.62	28.76	6.23	6.47	15.26	9.03
1662-16-20 Avg.	7.32	10.90	24.61		5.19	5.66	9.36	
1662-16 ( ) 043-16	7.06	8.52	13.73	6.67	4.28	4.64	5.21	0.57
( ) 046	7.96	9.22	16.32	8.36	3.90	5.15	5.87	0.72
( ) 050	8.63	12.18	26.61	7.98	4.51	5.56	7.37	2.86
( ) 054	8.62	11.07	18.93	10.31	5.56	7.98	15.21	9.65
1662-16-16 Avg.	8.07	10.25	18.90		4.56	5.83	8.42	
1663-20-( ) 034-22	5.30	6.08	9.93	4.63	5.70	5.65	9.40	3.70
( ) 037	6.61	8.71	21.12	14.51	5.67	6.60	8.05	2.38
( ) 040	7.24	8.70	17.59	10.35	6.51	6.85	16.51	10.00
( ) 043	6.59	7.45	22.39	15.80	7.46	7.85	16.32	8.86
1663-20-22 Avg.	6.48	7.74	17.76		6.34	6.74	13.02	

Contact Type	Contact Size	Indentor Spacing	Wire Size	Single Indent VD_B	Single Indent VD_E	Single Indent VD_S	ΔVD	Double Indent VD_B	Double Indent VD_E	Double Indent VD_S	ΔVD
1663	-20	( ) 037	-20	5.47	6.73	17.41	11.94	5.57	6.78	8.83	3.26
		( ) 040		6.27	7.52	19.31	13.04	6.50	6.97	16.01	9.51
		( ) 043		8.42	15.30	30.78	22.36	6.00	7.00	25.70	19.70
		( ) 046		8.03	12.29	35.02	26.99	6.72	6.53	25.36	18.64
1663-20-20 Avg.				7.05	10.46	25.63		6.20	6.82	18.98	
1663	-16	( ) 037	-20	4.73	5.77	7.45	2.72	5.40	5.07	6.47	1.07
		( ) 040		5.17	7.35	9.67	4.50	4.42	5.58	6.38	1.96
		( ) 043		6.15	8.37	17.35	11.20	5.08	6.06	10.32	5.24
		( ) 046		6.80	8.95	13.62	6.82	5.44	6.56	14.87	9.43
1663-16-20 Avg.				5.71	7.61	12.02		5.09	5.82	9.51	
1663	-16	( ) 043	-16	6.97	10.04	13.42	6.45	4.22	5.57	6.16	1.94
		( ) 046		7.06	10.00	15.69	8.63	4.17	5.49	5.40	1.23
		( ) 050		9.53	13.12	19.57	10.04	4.65	6.40	6.76	2.11
		( ) 054		9.34	12.64	25.22	15.88	5.08	8.63	11.37	6.29
1663-16-16 Avg.				8.23	11.45	18.48		4.53	6.52	7.42	
3192	-20	( ) 034	-22	7.65	6.11	7.18	-0.47	5.62	6.05	6.47	0.85
		( ) 037		5.71	7.19	6.52	0.81	5.99	7.02	7.89	1.90
		( ) 040		6.18	7.02	9.77	3.59	7.38	7.11	9.33	1.95
		( ) 043		5.95	7.73	7.46	1.51	6.65	9.52	10.83	4.18
3192-20-22 Avg.				6.37	7.01	7.76		6.41	7.43	8.63	
3192	-20	( ) 037	-20	5.32	7.82	10.43	5.11	5.95	6.07	7.56	1.61
		( ) 040		6.20	8.95	14.52	8.32	5.95	6.17	14.70	8.75
		( ) 043		6.47	10.91	29.79	23.32	5.75	7.06	11.35	5.60
		( ) 046		6.67	11.65	26.64	20.02	6.06	6.78	8.16	2.10
3192-20-20 Avg.				6.15	9.83	20.35		5.93	6.52	10.44	

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent VD_B	Single Indent VD_E	Single Indent VD_S	ΔVD	Double Indent VD_B	Double Indent VD_E	Double Indent VD_S	ΔVD
3192-16 ( ) 037-20	6.40	7.75	8.07	1.67	4.15	4.51	25.96	21.81
( ) 040	5.11	5.44	7.21	2.10	4.85	4.60	5.17	0.32
( ) 043	6.43	6.99	9.53	3.10	5.03	5.51	7.17	2.14
( ) 046	7.23	10.06	22.66	15.43	5.45	6.12	7.98	2.53
3192-16-20 Avg.	6.29	7.56	11.87		4.87	5.19	11.57	
3192-16 ( ) 043-16	6.37	7.32	9.29	2.92	3.65	4.28	4.66	1.01
( ) 046-16	6.27	9.05	9.67	3.40	4.14	6.09	5.96	1.82
( ) 050	7.08	11.52	14.10	7.02	4.66	6.20	7.22	2.56
( ) 054	10.15	11.50	18.46	8.31	5.63	6.96	9.11	3.48
3192-16-16 Avg.	7.47	9.85	12.88		4.52	5.88	6.74	
3193-20 ( ) 034-22	6.00	9.17	9.97	3.97	4.89	5.32	6.05	1.16
( ) 037	4.64	5.86	6.64	2.00	5.44	5.92	7.97	2.53
( ) 040	5.93	8.71	10.92	4.99	5.87	8.00	8.87	3.00
( ) 043	5.95	6.29	7.94	1.99	7.07	8.02	10.42	3.35
3193-20-22 Avg.	5.63	7.52	8.87		5.82	6.82	8.33	
3193-20 ( ) 037-20	4.87	7.92	9.20	4.33	5.45	6.45	6.69	1.24
( ) 040	8.31	7.62	11.08	2.77	5.97	7.74	8.32	2.35
( ) 043	8.57	11.55	15.35	6.78	6.37	7.51	8.62	2.25
( ) 046	6.83	9.87	12.54	5.71	6.97	6.53	7.05	0.08
3193-20-20 Avg.	7.15	9.24	12.04		6.19	7.06	7.67	
3193-16 ( ) 037-20	4.65	6.07	5.69	1.04	4.42	5.23	5.49	1.07
( ) 040	5.60	6.77	6.27	0.67	4.66	4.98	5.34	0.68
( ) 043	6.27	5.65	6.66	0.39	5.29	5.39	5.64	0.35
( ) 046	6.02	7.30	7.72	1.70	5.85	5.94	6.08	0.23
3193-16-20 Avg.	5.64	6.45	6.59		5.06	5.39	5.64	

Contact Type	Contact Size	Indentor Spacing	Wire Size	Single Indent VD_B	Single Indent VD_E	Single Indent VD_S	ΔVD	Double Indent VD_B	Double Indent VD_E	Double Indent VD_S	ΔVD
3193	-16	( )	043-16	6.27	8.17	10.85	4.58	3.62	4.53	4.51	0.89
		( )	046	6.80	7.51	9.27	2.47	3.92	4.20	4.97	1.05
		( )	050	6.14	8.98	10.94	4.80	4.35	5.17	6.27	1.92
		( )	054	5.31	8.67	14.88	9.57	4.37	6.68	8.02	3.65
3193-16-16 Avg.				6.13	8.33	11.49		4.07	5.15	5.94	
CEPI	-20	( )	034-22	4.35	5.07	5.13	0.78	4.73	5.81	4.79	0.06
		( )	037	4.22	4.97	5.17	0.95	5.60	6.41	6.07	0.47
		( )	040	4.42	5.01	5.39	0.97	5.39	6.76	5.93	0.54
		( )	043	4.85	5.98	5.99	1.14	5.96	6.44	6.13	0.17
CEPI-20-22 Avg.				4.46	5.26	5.42		5.42	6.36	5.73	
CEPI	-20	( )	037-20	5.90	5.56	4.97	-0.93	5.55	6.27	5.73	0.18
		( )	040	4.42	5.75	5.10	0.68	6.25	6.16	5.33	-0.92
		( )	043	4.99	5.90	5.22	0.23	5.87	5.80	5.40	-0.47
		( )	046	5.93	5,73	5.24	-0.69	6.10	6.19	5.17	-0.93
CEPI-20-20 Avg.				5.31	5.74	5.13		5.94	6.11	5.41	
CEPI	-16	( )	037-20	5.23	5.43	5.32	0.09	4.51	4.95	5.18	0.67
		( )	040	6.31	6.91	8.05	1.74	5.10	5.28	5.08	-0.02
		( )	043	5.73	6.90	6.77	1.04	5.88	5.68	5.97	0.09
		( )	046	6.90	6.20	6.36	-0.54	6.95	5.85	6.31	-0.64
CEPI-16-20 Avg.				6.04	6.36	6.63		5.61	5.44	5.64	
CEPI	-16	( )	043-16	4.18	4.04	5.02	0.84	3.90	3.35	4.00	0.10
		( )	046	4.92	4.40	5.74	0.82	3.92	3.54	4.02	0.10
		( )	050	4.43	5.15	6.97	2.54	4.05	3.38	4.13	0.08
		( )	054	5.04	5.76	8.27	3.23	4.49	4.53	5.54	1.05
CEPI-16-16 Avg.				4.64	4.84	6.50		4.09	3.70	4.42	

Contact Type / Contact Size / Indentor Spacing / Wire Size	Single Indent VD_B	Single Indent VD_E	Single Indent VD_S	ΔVD	Double Indent VD_B	Double Indent VD_E	Double Indent VD_S	ΔVD
CESO-20 ( ) 034-22	3.87	5.58	4.95	1.08	5.55	6.47	6.37	0.82
( ) 037	4.17	5.10	4.79	0.62	6.18	7.42	7.30	1.12
( ) 040	6.11	6.26	6.08	-0.03	7.75	6.56	8.19	0.44
( ) 043	6.36	6.57	10.04	3.68	6.90	6.31	7.91	1.01
CESO-20-22 Avg	5.13	5.88	6.47		6.60	6.69	7.41	
CESO-20 ( ) 037-20	4.68	4.88	5.25	0.57	5.87	5.66	5.76	-0.11
( ) 040	4.99	5.10	4.67	-0.32	5.27	6.09	4.98	-0.29
( ) 043	5.80	6.32	7.03	1.23	5.63	5.12	5.05	-0.58
( ) 046	6.34	5.84	7.44	1.10	7.07	6.46	6.43	-0.64
CESO-20-20 Avg	5.45	5.54	6.10		5.96	5.83	5.55	
CESO-16 ( ) 037-20	5.75				4.77			
( ) 040	5.67				4.66			
( ) 043	6.26				5.97			
( ) 046	7.28				7.24			
CESO-16-20 Avg	6.24				5.66			
CESO-16 ( ) 043-16	4.59	5.77	5.82	1.23	4.47	5.11	4.97	0.50
( ) 046	5.41	6.32	7.49	2.08	4.50	5.31	4.45	-0.05
( ) 050	5.82	6.36	7.44	1.62	5.08	6.05	6.27	1.19
( ) 054	6.64	7.87	9.23	2.59	4.98	6.11	6.06	1.08
CESO-16-16 Avg	5.62	65.80	7.50		4.76	5.65	5.44	

APPENDIX E

A STUDY OF THE EFFECTS OF INDENT CONFIGURATION UPON THE TENSILE STRENGTH OF CRIMPED CONNECTIONS

used in

A Study for the Determination of
the Indent Depth and Configuration for
the Maximum Reliability Connections When
Nickel Plated Copper Wire is Crimped
into Gold Plated Connector Contacts

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May 1967

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A STUDY OF THE EFFECTS OF INDENT CONFIGURATION UPON THE TENSILE STRENGTH OF CRIMP CONNECTIONS

1. INTRODUCTION

This report describes and presents the results of a study of the effects of two different indent configurations upon the tensile strength and variability in tensile strength of crimp connections made using nickel-plated copper wire in gold-plated connector contacts. The study was conducted by Melpar, Inc., Falls Church, Virginia, for the Marshall Space Flight Center under Contract NAS8-2047. The study was part of a broader study entitled "Indent Depth and Configuration Study for Maximum Reliability Connections of Nickel-plated Copper Wire in Gold-plated Connector Contacts."

2. PURPOSE

The purpose of the study described herein was to test the following two research hypotheses.

2.1 Hypothesis I

Crimp connections, made using selected types of connectors and selected combinations of contact size, wire size, and indentor spacing, have a greater tensile strength when a double indent is used in making the connections than when a single indent is used.

2.2 Hypothesis II

Crimp connections, made using selected types of connectors and selected combinations of contact size, wire size, and indentor spacing, have a greater uniformity in tensile strength when a double indent is used in making connections than when a single indent is used.

3. UNIVERSE OF DISCOURSE

The universe of discourse for this study consisted of those crimp connections made using the materials and combinations of materials specified in the contract statement of work. The results of the study are directly applicable to this population of crimp connections. Caution should be exercized in generalizing the results of this study to populations of crimp connections made using materials and/or combinations of materials not specifically included in the present study.

4. METHODS AND PROCEDURES

The following subsections summarize the methods and procedures used in the study.

4.1 General

The study consisted essentially of comparing the average tensile strength of two matched samples of crimp connections made using various combinations of connector types, contact sizes, wire sizes, and indentor spacings. One of the samples was made using a single indent and the other was made using a double ident. The research hypothesis for the study was that the double indent configuration would result in crimp connections having a greater (average) tensile strength than that of crimp connections made using a single indent configuration. The statistical significance of the observed differences in the tensile strength of the two samples was assessed by the Wilcoxon Matched-pairs Signed-ranks Test. The rejection region for the null hypothesis was one-tailed, and the significance level (α) for the test was set at 0.025 (see section 5.3). This nonparametric statistical test was selected as an alternative to the parametric t-test because there was evidence that the sample observations were drawn from non-normally distributed and non-homoscedastic populations. The Wilcoxon Test has an asymptotic power-efficiency of $3/\pi = 95.5$ percent compared with the t-test when the underlying assumptions of the the t-test are in fact met.

4.2 Identification of Variables

The following were established as the relevant variables for the study.

4.2.1 Dependent Variable

The dependent variable for the study was the tensile strength of the crimp connections. Tensile strength was tested in accordance with MIL-T-22520B.

4.2.2 Independent Variable

The independent variable for the study was the indent configuration used in making the crimp connections. Two indent configurations were investigated: (a) a single indent and (b) a double indent.

4.2.3 Controlled Conditions

Control was exercised over the following variables which may have an effect upon the tensile strength of crimp connections. The method of control was to use samples which were matched with respect to these variables.

4.2.3.1 Connector Type: Each of the matched samples included six different types of connectors with gold-plated contacts. These six connectors may be classified into three different connector pairs each consisting of a male and a female connector. The six connectors and three connector pairs were:

Pair	Male	Female
I	NAS 1662	NAS 1663
II	MS 3192	MS 3193
III	Bendix CEPI	Bendix CESO

All connectors of a given type (i.e., NAS, MS, Bendix) were of the same manufacture which served as a control over any variability in tensile strength that might be attributable to differences between connectors of different manufacture. In making the samples of crimp connections, connectors were selected at random from those purchased, thus randomizing between the two experimental conditions (i.e., indent configurations) any remaining variability in properties of the connectors that might have an effect upon the tensile strength of the connections.

4.2.3.2 Contact Size: Two different contact sizes were used for each of the six types of connectors. These were a size 20 and a size 16 contact.

4.2.3.3 Wire: All crimp connections were made using nickel-plated copper wire conforming to MIL-C-27500. Three different wire sizes were used in the study: sizes 22, 20, and 16. The same combinations of contact size and wire size were used in both samples. These combinations were:

Contact Size	Wire Size
20	22
20	20
16	20
16	16

The wire used in making the samples of crimp connections was obtained from several different sources of supply. Although all wire conformed to MIL-C-27500, the possibility exists that wire from different manufacturers may have variations in certain properties that affect the tensile strength of crimp connections made using the wire. Unfortunately, this was not recognized when the samples of crimp connections were being prepared, and no records were kept to identify which connections were made with wire from which source. Fortunately, upon reviewing the procedures followed in assembling the two samples of connections, it appears reasonable to assume that wire from the same source was, in fact, used in preparing each of the pairs of connections made using the same combinations of connector type, contact size, wire size, and indentor spacing (see 4.2.3.4). Consequently, it seems reasonable to assume that the two samples were matched across the two experimental conditions with respect to the source of wire used in making the crimp connections.

4.2.3.4 Indentor Spacing: Seven different indentor spacings (Dimension A, MS 3191) were used in making each of the two samples of crimp connections. These were: (a) 0.034", (b) 0.037", (c) 0.040", (d) 0.043", (e) 0.046", (f) 0.050", and (g) 0.054". Four of the seven different indentor spacings were used for each of the combinations of connector type, contact size, and wire size used in the study. The specific four indentor spacings used in a given combination varied as a function of the wire size used in the combination. The four indentor spacings used with each wire size were:

Wire Size	Indentor Spacings			
22	0.034"	0.037"	0.040"	0.043"
20	0.037"	0.040"	0.043"	0.046"
16	0.043"	0.046"	0.050"	0.054"

4.2.3.5 Total Number of Combinations of Materials and Indentor Spacings: A total of 92 different combinations of connector types, contact sizes, wire sizes, and indentor spacings were available in matched samples.

4.2.3.6 Fabrication of Samples of Crimp Connections: Standardized procedures were followed in preparing the two samples of crimp connections. Since the fabrication procedures were standardized, it may be reasonably assumed that the two samples of connections were matched with respect to any variables attributable to the method of fabrication which may have an effect upon the tensile strength of the crimp connections.

4.2.3.7 Measurement of Dependent Variable: To obtain a typical measurement of the tensile strength of crimp connections made using a specific connector type/contact size/wire size/indentor spacing combination, 30 specimen crimp connections were made for each of the 92 combinations of these variables under each of the two indent configurations. Within each of these 184 subsamples (i.e., 92 with a single and 92 with a double indent) of 30 specimens, all connections were made using materials, methods, etc., that were as homogeneous as could possibly be achieved within practical limitations. Each of the 30 specimens within each of the 184 subsamples was tensile tested using standardized procedures in accordance with MIL-T-22520B, and the arithmetic mean tensile strength for the 30 specimens was calculated and used as the typical measurement of tensile strength for the particular combination of materials, indentor spacing, and indent configuration.

5. SYNOPSIS OF STUDY

The study consisted essentially of comparing the tensile strength and relative variability in tensile strength of two matched samples of crimp connections. One of these samples was made using a single indent while the other was made using a double indent. Separate pairs of matched samples were made using each of six different connectors and various combinations of contact size, wire size, and indentor spacing. The research hypotheses were tested individually for applicability to crimp connections made using each of these six types of connectors.

5.1 The Samples of Crimp Connections

The six types of connectors used in the study were the NAS 1662, NAS 1663, MS 3192, MS 3193, Bendix CEPI, and Bendix CESO. Each of the two samples of crimp connections made with each of the six different connectors included four different combinations of contact size and wire size, and four different indentor spacings (see sections 4. 2. 3. 3 and 4. 2. 3. 4).

5.2 Measurement of the Dependent Variables

To obtain a representative measurement of the tensile strength of crimp connections made using a specific connector and a specific combination of contact size, wire size, and indentor spacing, sixty crimp connections were made for each combination of connector type, contact size, wire size, and indentor spacing. Thirty of these connections were made using a single indent, and 30 were made using a double indent. Each of these two subsamples of 30 connections was tensile tested in accordance with MIL-T-22520B, and a measurement of the tensile strength of each of the 30 specimen connections was obtained. The arithmetic mean and standard deviation of these samples of 30 measurements were computed. The sample mean was used as the best available estimate of the tensile strength of crimp connections made with the specific type of connector, the specific combination of contact size, wire size and indentor spacings, and the specific indent configuration represented by the sample of 30 connections. The ratio of the sample standard deviation to the sample mean (i.e., the coefficient of relative variability) was used as the best estimate of the relative variability of crimp connections made using the materials, combination of materials, indentor spacing, and indent configuration represented by the sample of 30 connections.

5.3 Data Analysis

To assess the effect of indent configuration upon the tensile strength of crimp connections, the sample means (obtained as described above) were cast into six matrices each consisting of 2 columns and 16 rows (table 1). Each of these six matrices corresponds to one of the six different connectors used in the study. Within a matrix, each column corresponds to one of the two indent configurations investigated, while each row corresponds to one of the 16 different combinations of contact size,

TABLE 1

REPRESENTATION OF GENERAL DESIGN OF THE STUDY WITH RESPECT TO THE EFFECTS OF INDENT CONFIGURATION

Connector: XX XXXX

Contact Size	Wire Size	Indentor Spacing	Indent Configuration Single	Indent Configuration Double
20	22	0.034"	X_{11}	X_{21}
		0.037"	X_{12}	X_{22}
		0.040"	X_{13}	X_{23}
		0.043"	X_{13}	X_{23}
20	20	0.037"		
		0.040"		
		0.043"		
		0.046"		
16	20	0.037"		
		0.040"		
		0.043"		
		0.046"		
16	16	0.043"		
		0.046"		
		0.050"	X_{13}	X_{23}
		0.054"	X_1 (16)	X_2 (16)

NOTE: Cell entries, X_{ij}, were sample arithmetic mean tensile strengths in study of tensile strength and sample coefficients of relative variability in study of variability in tensile strength.

wire size, and indentor spacing used in making the crimp connections. Within a given row of the matrix, the cell entries are the sample mean tensile strengths obtained from the specimen connections made using the combination of materials, indentor spacing, and indent configuration represented by the particular cell in the matrix.

Once the matrices had been prepared, the algebraic differences in tensile strength between the two cell entries in each row were calculated. In performing the subtraction, the tensile strengths in the single indent column were subtracted from the corresponding tensile strengths in the double indent column. Thus, a difference in the direction predicted by the research hypothesis (section 2. 1) had a positive sign while a difference in a direction opposite to that predicted by the research hypothesis would have a negative sign. The statistical significance of the observed differences in tensile strength was assessed using the Wilcoxon Matched-pairs Signed-ranks Test to test the null hypothesis that the true difference in tensile strength between crimp connections made using a double indent and those made using a single indent is zero. The significance level (α) for the Wilcoxon Test was set at 0.025. The values of N used in the test are reported in table 2. The region for rejection of the null hypothesis was one-tailed due to the directional prediction made in the research hypothesis (section 2. 1).

The procedure used to assess the effect of indent configuration upon the relative variability in tensile strength of crimp connections was basically the same as that described above. In this case the cell entries in the matrices were the computed coefficients of relative variability for the 30 specimens of connections represented by each particular cell in the matrix. The algebraic differences between the coefficients of relative variability in each row were calculated by subtracting the cell entries in the single indent column from those in the double indent column. In this instance a difference in the direction predicted by the research hypothesis II (section 2.2) had a negative sign indicating less variability and, hence, greater uniformity in tensile strength with a double indent.

The statistical significance of the observed differences was again tested by means of the Wilcoxon Test. The null hypothesis tested was that the true difference in relative variability between crimp connections made using a double indent and those made using a single indent is zero. The significance level (α) for the test was set at 0.025. The values of N used in the test are reported in table 3. The region for rejection of the null hypothesis was one-tailed due to the directional prediction made in the research hypothesis.

6. SUMMARY OF RESULTS

In general, the results of the study supported the conclusion that the tensile strength of crimp connections made using any of the types of connectors included in the study is both greater and more uniform when a double indent is used in making the connections than when a single indent is used. The single exception to this general conclusion is the Bendix CESO connector. The tensile strength and relative variability in tensile strength of crimp connections made using this connector were both unaffected by the indent configuration used in making the connections. The reasons for the obtained results with the Bendix CESO connector are not readily apparent.

6.1 Effect on Tensile Strength

Table 2 summarizes the results of the study with respect to the effect of indent configuration upon the tensile strength of crimp connections. The table presents the arithmetic mean and median tensile strengths for each of the two sample distributions of tensile strengths obtained for each of the six connectors included in the study (i.e., the means and medians are for the single and double indent columns in the observation matrices for each connector). The table also shows the percentage changes in the mean and median tensile strengths in going from a single to a double indent configuration.

In examining table 2, it will be noted that, with the single exception of the Bendix CESO connector, the mean tensile strengths obtained with a double indent are greater than those obtained with the single indent. In the case of the Bendix CEPI connector, the percentage increase in going from a single to a double indent is considerably less than it is for either the NAS or MS connectors. The slight decrease in tensile strength shown for the Bendix CESO connector in going from a single to a double indent is negligible.

An inspection of the median values in table 2 reveals that in all instances the median tensile strengths obtained with a double indent are greater than those obtained with a single indent. Again, in the case of the Bendix CEPI connector, the percentage increase in tensile strength in going from a single to a double indent is considerably less than for either the NAS or MS connectors. The slight increase in tensile strength shown for the Bendix CESO connector in going from a single to a double indent is negligible.

Although the observed differences between the tensile strengths obtained using a single and a double indent with the Bendix CEPI connector are statistically significant differences, the fact that the connections made with the Bendix CEPI showed such a small percentage increase in tensile strength in going from a single to a double indent, compared to the NAS and MS connectors combined with the fact

TABLE 2

SUMMARY OF RESULTS OF STUDY OF THE EFFECTS OF INDENT CONFIGURATION UPON THE TENSILE STRENGTH OF CRIMP CONNECTIONS

Average Tensile Strength[1] and Percent Change In Average

	Mean[2]			Median[2]			Wilcoxon Test		
	Indent			Indent					
Connector	Single	Double	% Change	Single	Double	% Change	T	N	α^3
NAS 1662	32.4	38.6	19.1	30.1	35.7	18.6	5	16	0.005*
NAS 1663	29.8	38.2	28.2	29.5	34.6	17.3	0	16	0.005*
MS 3192	33.7	40.0	18.7	31.1	35.9	15.4	0	16	0.005*
MS 3193	32.3	38.0	17.6	28.6	32.2	12.6	8	16	0.005*
Bendix CEPI	33.3	35.5	6.6	26.8	28.8	7.5	30	16	0.025*
Bendix CESO	34.9	34.8	-0.3	28.8	29.1	1.0	41	12	>0.025

NOTES:

1. Tensile strengths are in pounds.

2. Mean and medians are for distributions of sample means obtained using each indent configuration for each connector and take into account all combinations of contact size, wire size, and indentor spacing used in making the connections. Values are based on 16 observations except for the Bendix CESO connector where the values are based on 12 observations.

3. An asterisk (*) indicates that the research hypothesis was accepted.

that the differences obtained with the Bendix CESO connector were not statistically significant, suggests that in the study some factor was operative that tended to minimize the effect of changes in indent configuration upon the tensile strength of the crimp connections made with these connectors. It is not readily apparent what this factor was. Since the contact sizes, wire sizes, type of wire, and indentor spacings used in making the crimp connections with the Bendix connectors were the same as those used with the NAS and MS connectors, it appears likely that the factor is some inherent property of the design of or materials used in making Bendix connectors. However, it may be that the factor is some other unidentified variable or some interaction effect among variables. Possibly the indentor spacings used in making the connections were not as ideally suited for use with the Bendix connectors as they were for use with the NAS and MS connectors which may have tended to minimize the effects of the differences in indent configuration.

At this point it should be noted that, due to an oversight, the original samples of crimp connections made with the Bendix CESO connector did not include connections made using a size-16 contact and a size-20 wire. The effect of this oversight was to reduce the number of paired observations of tensile strength from the 16 pairs available for all other connectors to 12 for the Bendix CESO connector. It does not appear, however, that the results of the study with respect to the Bendix CESO connector can be attributed to the failure to obtain the four pairs of measurements of tensile strength using the size-16 contact and size-20 wire and the associated indentor spacings. Once the oversight was discovered, the "missing" samples of crimp connections were, in fact, prepared and the required measurements of tensile strength obtained. However, inclusion of the data from these samples with the original data and re-evaluation of the overall data then available did not alter the findings with respect to the Bendix CESO connector. The effects of inclusion of the additional data upon the means and medians reported in table 2 were negligible. With the added data, the means for single and double indents were 32.8 and 33.2 pounds, respectively, compared to the values 34.9 and 34.8 pounds shown in table 2. With the added data, the median values for the single and double indent were 27.5 and 30.2 pounds, respectively, compared to the 28.8 and 29.1 pounds reported in table 2.

It will be noted in table 2 that in all instances the mean tensile strengths are greater than the corresponding median tensile strengths. This is attributable to the fact that the sample distributions of measurements included measurements from connections made using three different wire sizes and that the wire sizes used each had a significant differential effect upon the tensile strength of the connections made with the connectors, with tensile strength increasing as a function of increasing wire size. The approximate average percentage increase in tensile strength in going from a size-22 to a size-20 wire was 40.7 percent. The corresponding average percentage increase in tensile strength in going from a size-20 to a size-16 wire was 87.4 percent. The average percentage increase in going from a size-22 to a size-16 wire as 163.2 percent. The large difference in tensile strength between connections made with size-16 wire and those made with either the size-22 or size-20 wires tended to produce positive skewness in the sample distributions. This skewness is what is reflected by the difference between the mean and median values in table 2. It should be noted, however, that this has no effect upon the results of the study with respect to the conclusions that may be drawn concerning the effects of indent configuration upon the tensile strength of the crimp connections.

Table 2 also presents the results of the Wilcoxon Test applied to the observed differences in tensile strength between each of the matched samples of connections. The table presents the computed value of the test statistic T used in the Wilcoxon Test, the value of N (the number of paired observations having a difference in tensile strength other than zero), and the significance level (α) at which the research hypothesis (section 2.1) may be accepted. An asterisk after the reported value indicates that the value falls within regions established in the study for rejection of the null hypothesis and acceptance of the research hypothesis. The table shows that the research hypothesis was accepted for all connectors except the Bendix CESO.

6.2 Effects on Uniformity in Tensile Strength

Table 3 summarizes the results of the study with respect to the effect of indent configuration upon the relative variability in tensile strength of crimp connections. The organization of the table is the same as that for table 2. The data reported are based upon the two sample distributions of coefficients of relative variability obtained for each of the six connectors included in the study.

In examining table 3, it will be noted that for all connectors the mean coefficients of relative variability obtained with a double indent are less than those obtained with a single indent. With the exception of the Bendix CESO connector, the observed differences in the relative variability in tensile strength were statistically significant.

Inspection of the median values reported in the table reveals that for all connectors except the Bendix CESO connector the median coefficients of relative variability obtained with a double indent are less than those obtained with a single indent. In the case of the Bendix CESO connector, the slight increase in relative variability in going from a single to a double indent is negligible.

It will be noted that the percentage change in average variability in going from a single to a double indent is less for Bendix CEPI connector than for the NAS and MS connectors. This fact combined with the failure to observe significant differences in relative variability in going from a single to a double indent with the Bendix CESO connector again suggests, as it did in the case of the effects of indent configuration on tensile strength, that some factor was operative in the study that acted to minimize the effect of the different indent configurations when the Bendix connectors are used.

TABLE 3

SUMMARY OF RESULTS OF STUDY OF THE EFFECTS OF INDENT CONFIGURATION UPON THE RELATIVE VARIABILITY IN TENSILE STRENGTH OF CRIMP CONNECTIONS

Average Relative Variability[1] In Tensile Strength and Percent Change In Average

Connector	Mean[2]			Median[2]			Wilcoxon Test		
	Indent			Indent					
	Single	Double	% Change	Single	Double	% Change	T	N	α[3]
NAS 1662	6.14	2.13	-65.3	5.82	2.07	-63.9	0	16	0.005*
NAS 1663	6.51	2.35	-63.9	5.87	2.25	-61.7	0	16	0.005*
MS 3192	4.07	2.95	-27.5	4.02	2.28	-43.3	26.5	16	0.025*
MS 3193	5.72	3.11	-45.6	5.42	2.77	-48.9	9	16	0.005*
Bendix CEPI	4.44	3.52	-20.7	3.59	2.92	-18.7	29	16	0.025*
Bendix CESO	5.62	5.40	-3.91	5.16	5.58	*8.14	33	12	>0.025

NOTES:

1. Coefficients of relative variability have been multiplied by 100 to avoid small decimal fractions.

2. Means and medians are for distributions of sample coefficients of relative variability obtained using each indent configuration and take into account all combinations of contact size, wire size, and indentor spacing used in making the connections. Values are based on 16 observations except for the Bendix CESO connector where the values are based on 12 observations.

3. An asterisk (*) indicates that the research hypothesis was accepted.

The results of the Wilcoxon Test presented in table 3 show that the research hypothesis (section 2.2) was accepted for all connectors except the Bendix CESO.

7. INTERPRETATION OF RESULTS AND CONCLUSIONS

The results of the study indicate that, in general, the indent configuration used in making crimp connections has a significant differential effect upon the tensile strength and uniformity in tensile strength of the connections when the materials, combinations of materials, and indentor spacings used in making the connections are those specified in this report. The general effect is that a double indent configuration yields crimp connections that have a greater tensile strength and more uniformity in tensile strength than is obtained when a single indent is used in making the connections.

It appears that the magnitude of the effect in going from a single to a double indent is different for different connectors. The NAS connectors, taken together, appear to be the most affected by indent configuration in that crimp connections made with the NAS connectors tended to show the greater percentage increase in tensile strength and the greater percent decrease in relative variability in going from a single to a double indent. Similarly, the Bendix connectors, taken together, appear to be the least affected by indent configuration in that crimp connections made with these connectors tended to show the least percentage increase in tensile strength and the least percentage decrease in relative variability in going from a single to a double indent. In the case of the Bendix CESO connector, in fact, there was no significant change in either the tensile strength or its relative variability in going from a single to a double indent configuration.

8. CONCLUSIONS RELATING THE NAS 1662/1663 CONNECTORS

a. The tensile strength of crimp connections made using NAS 1662 connectors is greater than that of connections made using NAS 1663 connectors when a single indent configuration is used. However, this apparent difference in tensile strength between the two connectors is eliminated when a double indent configuration is used.

b. The tensile strength of crimp connections made using either of the NAS connectors is greater when a double indent is used in making the connections than when a single indent is used.

c. The tensile strength of crimp connections made using NAS connectors is significantly affected by the indentor spacing used in making the connections when the connections are made using a size-20 contact and size-22 wire. The effect is for tensile strength to decrease systematically as indentor spacing increases.

d. The tensile strength of crimp connections made using NAS connectors also appears to be significantly affected by the indentor spacing used in making the connections when the connections are made using a size-20 contact and a size-20 wire. In general, the effect is the same as for the size-20 contact and size-22 wire.

e. The tensile strength of crimp connections made using NAS connectors is not significantly affected by the indentor spacing used in making the connections when a size-16 contact is used in combination with either a size-20 or a size-16 wire.

f. The tensile strength of crimp connections made using NAS connectors is greater when a size-20 contact is used in combination with a size-20 wire than when the same contact size is used with a size-22 wire.

g. The tensile strength of crimp connections made using NAS connectors is greater when a size-16 contact is used in combination with a size-16 wire than when the same contact size is used with a size-20 wire.

h. The observation made above in f. and g. suggests that, for a given contact size, tensile strength is greater when a matching wire size is used in making the connections than when a wire size smaller than that of the contact is used.

i. The tensile strength of crimp connections made using NAS connectors is greater when a size-16 contact is used in combination with a size-20 wire than when a size-20 contact is used in combination with the same size wire. This suggests that, for a given wire size, tensile strength is greater when a contact that is slightly larger than the size of the wire is used in making the connections than when a contact the same size as the wire is used.

j. The tensile strength of crimp connections made using NAS connectors increases systematically as the sizes of the contacts and wire used in making the connections increase.

9. APPLICABILITY OF RESULTS

The results of this study are directly applicable to crimp connections made using the materials, combinations of materials, and indentor spacings included in this study. Caution should be exercised in generalizing the results of this study to crimp connections made using materials, combinations of materials, and indentor spacings other than those included in this study.